TELEOPERATOR MANEUVERING SYSTEM BENEFITS ASSESSMENT

VOLUME II — TECHNCAL REPORT

(NASA-CR-170796) TELEOPERATOR MANEUVERING SYSTEM BENEFITS ASSESSMENT, VOLUME 2 Final Report (Rockwell International Corp., Downey, Calif.) 262 p HC A12/MF A01 CSCL 05H G3/54
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Unclas 28209

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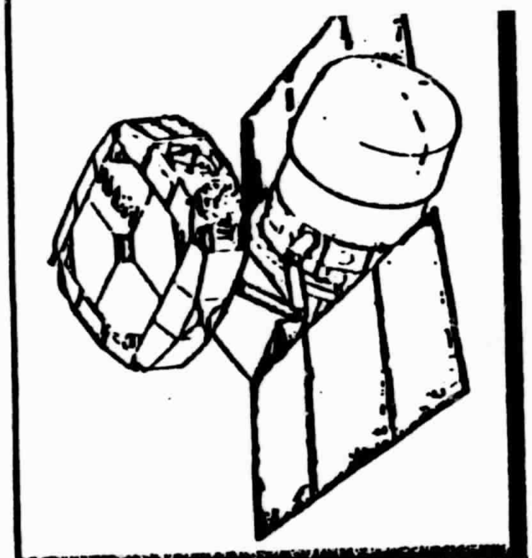

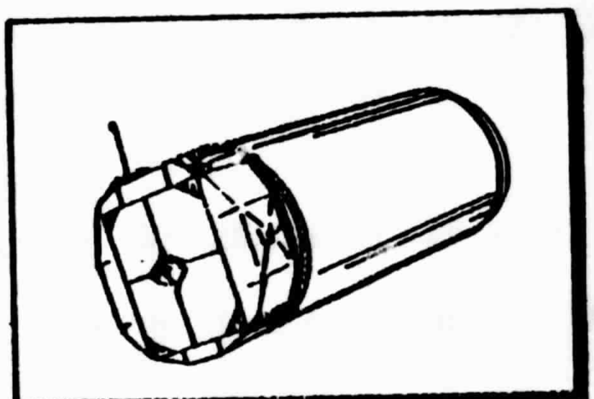

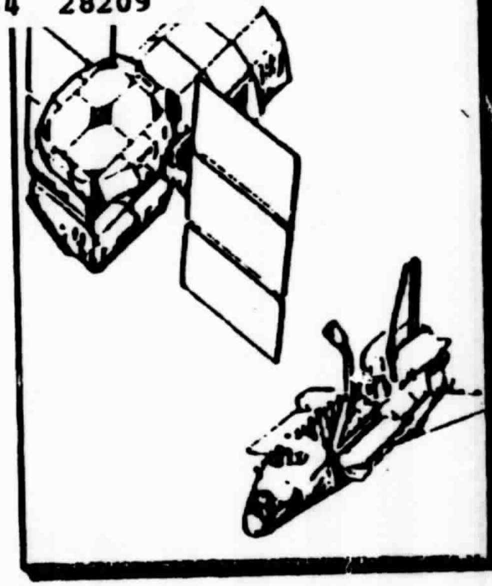

CONTRACT NO. NAS8-34888

Rockwell International

TELEOPERATOR MANEUVERING SYSTEM BENEFITS ASSESSMENT

VOLUME II - TECHNICAL REPORT

APRIL 1983

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PREPARED FOR THE

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ALABAMA 35812

BY

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TMS BENEFITS ASSESSMENT STUDY

PREFACE

This document contains material prepared by the Rockwell International Corporation for the final report on the Teleoperator Maneuvering System Benefits Assessment Study as defined in the statement of work, Contract NAS8-34888. The work was performed for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, for whom the Technical Manager is Mr. J. R. Turner, PS04.

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TMS BENEFITS ASSESSMENT STUDY

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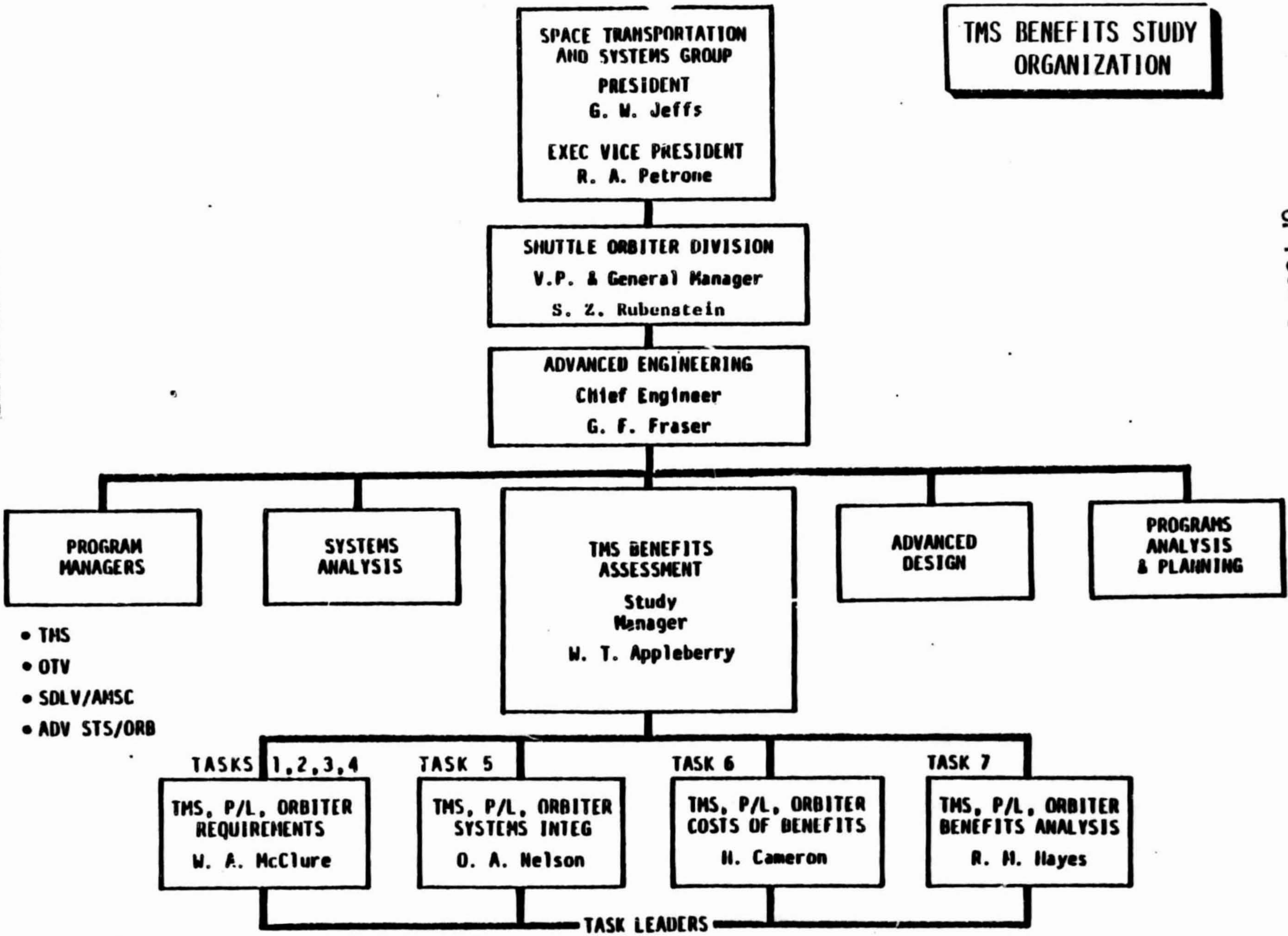
INTRODUCTION

- STUDY ORGANIZATION
- GUIDELINES AND ASSUMPTIONS
- CONCLUSIONS AND RECOMMENDATIONS

TMS BENEFITS STUDY ORGANIZATION



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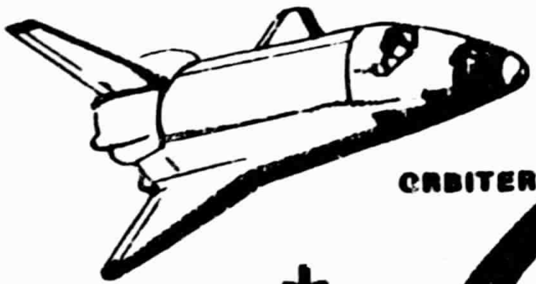
TMS BENEFITS ASSESSMENT STUDY

INTRODUCTION

Rockwell's interest in the TMS goes back several years when it was called the Teleoperator Retrieval System (TRS) and proposed its use in our approach to Skylab reboost. We have closely monitored its progress and were gratified to see renewed interest in its development in 1979/80. Rockwell sees in the TMS concept, the potential for a major enhancement of the Space Transportation System (STS). A strategy was developed in which we would exert every effort to encourage and support development of the TMS by working closely with the Marshall Space Flight Center and its contractors. After an evaluation of the status of TMS program definition, it was determined that a need existed for an economic benefits analysis which would cover the significant cost elements of TMS development, fleet acquisition, transport and operations, and trade studies comparing TMS with alternative means for satisfying mission requirements. An unsolicited proposal was made to MSFC and Rockwell was awarded a six month contract (NAS8-34888) valued at $78,400.



+

MSFC

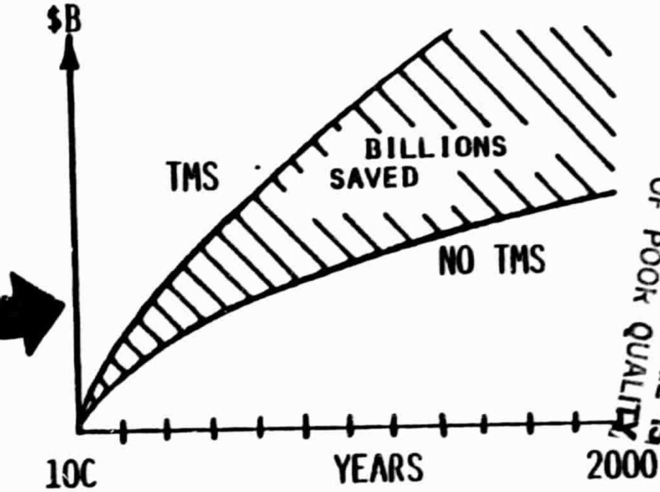
+

TMS

- STRATEGY

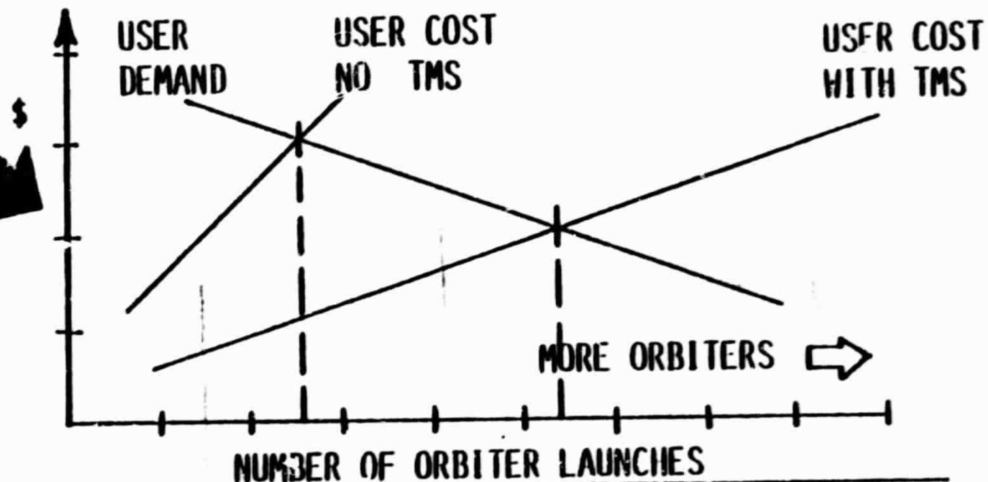
  WORK WITH MSFC AND CONTRACTORS

  SHOW VALUE OF TMS



- METHOD

  IDENTIFY ECONOMIC BENIFITS OF TMS TO USER/ORBITER/STS



SUPPORT TMS DEVELOPMENT

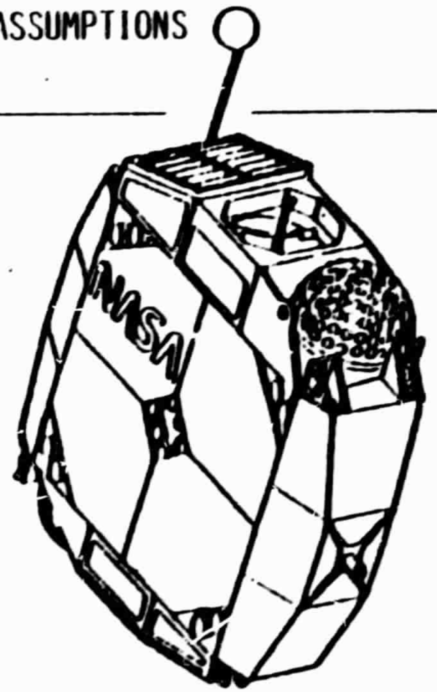
TMS BENEFITS ASSESSMENT STUDY

STUDY GUIDELINES AND ASSUMPTIONS

Rockwell proposed an unbiased evaluation of potential benefits of the Vought Corporation's Phase 'A' study TMS configuration, using Vought's acquisition costs as baseline. No new configurations were to be proposed. We did, however, also propose to conduct sensitivity studies of benefits versus an assumed change in acquisition costs, and versus changes in propellant capacity.

TMS BENEFITS ASSESSMENT STUDY
STUDY GUIDELINES AND ASSUMPTIONS

- PROVIDE UNBIASED EVALUATION OF VOUGHT PHASE "A" TMS CONFIGURATION
  - ✓ USE PHASE "A" CAPABILITIES AND ACQUISITION COSTS
  - ✓ PROPOSE NO NEW CONFIGURATIONS
- FOUR STUDY TASKS
  - MISSION MODELS/REQUIREMENTS
  - SYSTEMS INTEGRATION
  - COSTING
  - BENEFITS ANALYSIS



LENGTH/DIAMETER
37/156"

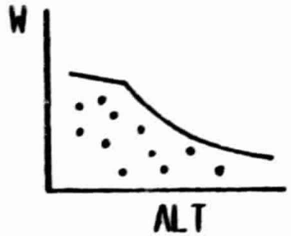
TOTAL WEIGHT
7545 LB

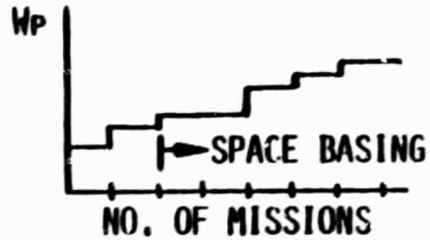
PROPELLANT
5000 LB

I_{SP} = 230 SEC.

✓ SUBTASK 4.1.4

EVALUATE PROPELLANT LOAD SIZING





✓ SUBTASK 4.3.2

ASSESS EFFECTS ON BENEFITS OF VARIATIONS IN ASSUMED COSTS/SCHEDULES

TMS BENEFITS ASSESSMENT STUDY

APPROACH AND STUDY PLAN

An economic analysis was selected as the approach to the study. This meant that certain uses for the TMS which were difficult to quantify would not be included in the analysis. These include debris removal and assembly operations, though the use of TMS for such tasks could become significant. It was determined that most TMS functions amenable to costing could be classified in three groups: Deployment, retrieval, and maintenance or servicing. The study plan consisted of four major tasks: Mission models and payload requirements, systems integration and analysis, costing of TMS and services, and an analysis of TMS benefits and costs versus alternatives to TMS. The study baseline TMS was ground based and operated in low earth orbits (150 to approximately 1500 nm). A parallel inhouse effort was mounted which examined potential benefits of space basing the TMS at LEO and performing missions to GEO. During the proposal preparations, Rockwell was awarded a contract to develop a 2-kit OMS tank assembly for the Orbiter payload bay. Thus, an evaluation of the OMS kit versus TMS was included in plans for the inhouse effort. About the time of contract award, however, the OMS kit effort was cancelled (an alternative to the kit, which was to be used for retrieval/repair/reboost of the Solar Maximum Satellite, was selected: A direct orbiter ascent to high altitude without need for the kit). This orbiter capability would also be analyzed for effect on TMS benefits.

TMS BENEFITS ASSESSMENT STUDY
APPROACH AND STUDY PLAN

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APPROACH

SHOW COST SAVINGS TO THE NATIONAL SPACE PROGRAM

STUDY PLAN

FOUR TASKS:
- MISSION MODELS/REQUIREMENTS
- SYSTEMS INTEGRATION
- COSTING
- BENEFITS ANALYSIS

CONTRACT
- GROUND BASED TMS
- REUSABLE TMS
- LEO MISSIONS

INHOUSE ACTIVITIES
- SPACE BASED TMS
- EXPENDABLE TMS
- OTV AND OMS KIT ISSUES
- USER FEE OPTIONS
- CONTINGENCY MISSIONS
- NEW MISSIONS

TMS BENEFITS ASSESSMENT STUDY

IS A NEW START JUSTIFIED?

Study results show that the ground based TMS provides benefits when used as a propulsion stage for payload deployment and retrieval, and for spacecraft maintenance. Further, these benefits are relatively insensitive to TMS investment costs because the STS launch charges dominate the total cost picture. Propulsion benefits depend upon the degree to which mission planning can include more than one TMS payload deployment, retrieval, or other propulsion service. Rockwell's initial confidence in TMS has been validated. The TMS would so enhance the space transportation system, it becomes the single most attractive addition to the STS inventory. Because TMS is an upper stage, its efficiency provides significant cost savings over the OMS kit, besides improving Orbiter efficiency at LEO by adding greater mission flexibility. Substantial additional benefits will be provided when the TMS can be space based. DOD is showing an interest in potential uses for TMS in deployment, retrieval, and maintenance of spacecraft. Three key missions are under examination: DMSP, GPS, and an R&D spacecraft. Additional DOD missions are being considered and Rockwell intends to develop this potential market for TMS.

IS A NEW START JUSTIFIED?

- TMS BENEFITS: SIGNIFICANT AND RELATIVELY INSENSITIVE TO INVESTMENT
- ROCKWELL'S VIEW: <u>THE</u> IMPORTANT SHUTTLE ENHANCEMENT
- PROVIDES EARLY COST SAVINGS FOR MULTIPLE PAYLOAD DEPLOYMENT COMPARED TO INTEGRAL PROPULSION
- ADDED COST BENEFITS THROUGH PAYLOAD SERVICING
- OUT PERFORMS ORBITER OMS KIT
- COST EFFECTIVENESS IMPROVED BY SPACE BASING
- EXPANDED POTENTIAL FOR DOD

JUSTIFIES EARLY TMS
PROGRAM START

TMS BENEFITS ASSESSMENT STUDY

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- STUDY OVERVIEW
- TECHNICAL DISCUSSIONS
  - TASK 4.1: MISSION MODELS AND PAYLOAD REQUIREMENTS
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  - TASK 4.4: TMS BENEFITS ANALYSIS

TMS BENEFITS ASSESSMENT STUDY

STUDY OVERVIEW

- TMS BASELINE CONFIGURATION
- TASK 4.1 - MISSION MODELS AND PAYLOAD REQUIREMENTS
- TASK 4.2 - SYSTEMS INTEGRATION
- TASK 4.3 - COSTING
- TASK 4.4 - BENEFITS ANALYSIS
- SPECIAL INTEREST STUDY TASKS

BASELINE TMS CONFIGURATION

The study baseline TMS configuration was developed by the Vought Corporation in their Phase A study contract (NAS8-33903), awarded by NASA/MSFC, and under the technical direction of Mr. J. R. Turner, COR.

BASELINE TMS CONFIGURATION

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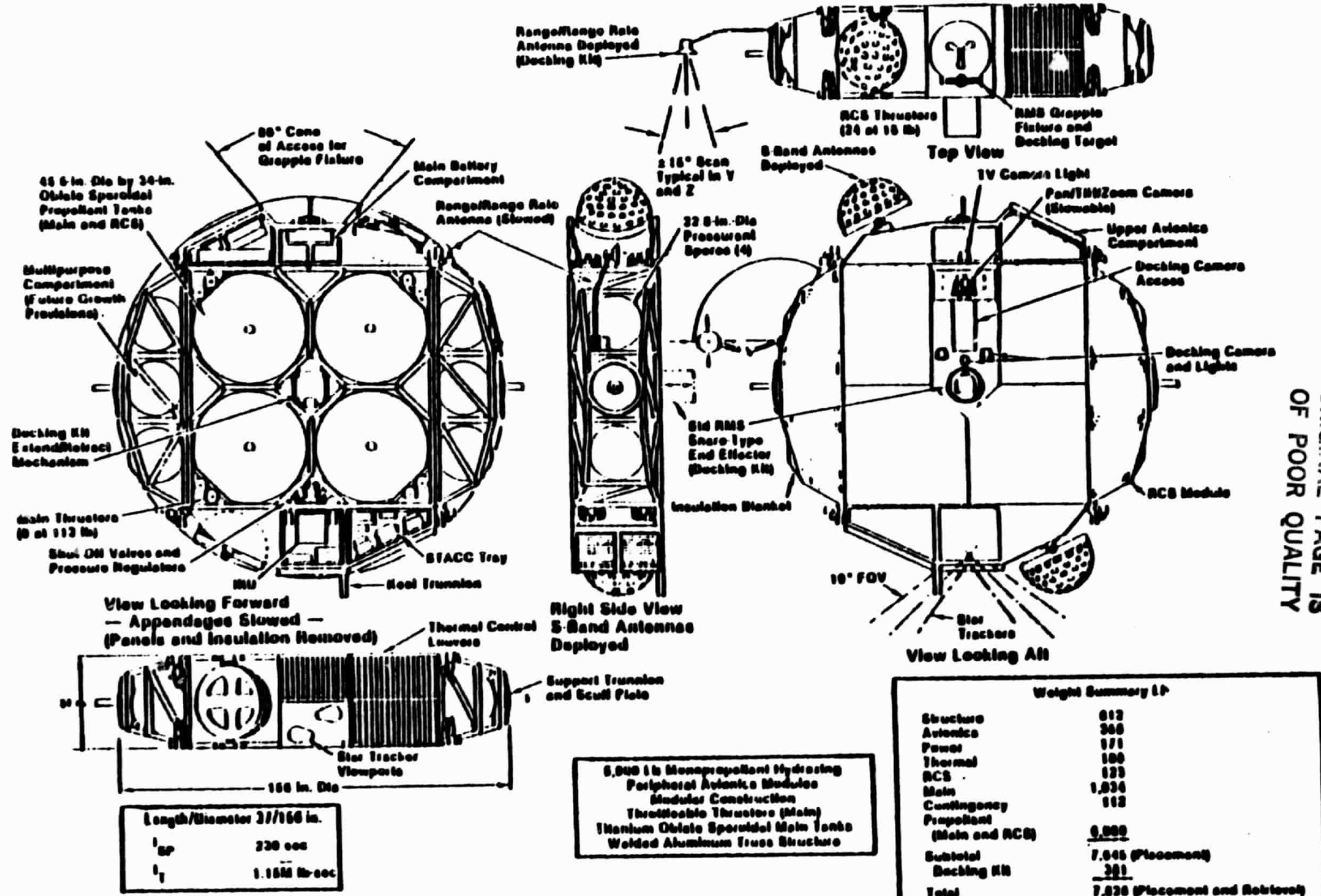


Weight Summary Lb

Structure	812
Avionics	360
Power	171
Thermal	180
RCS	123
Main	1,034
Contingency	112
Propellant (Main and RCS)	5,000
Subtotal	7,045 (Placement)
Docking Kit	391
Total	7,836 (Placement and Retrieval)

TMS BENEFITS ASSESSMENT STUDY

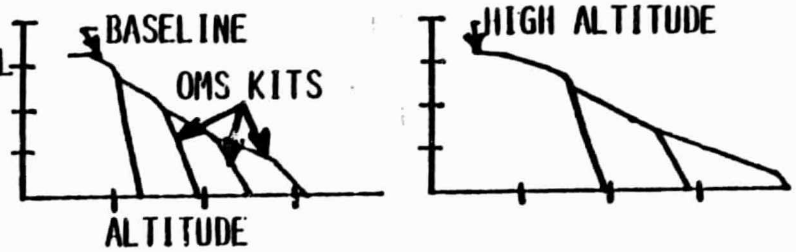
NEW ISSUES

During the course of the study, three new developments emerged which affected the TMS. The first two were directly related: A high altitude Orbiter ascent trajectory, under evaluation for some time but not approved for reasons of risk in external tank disposal and cargo manifesting limitations, was proposed for the Solar Maximum spacecraft repair mission. OMS kit development, initiated by NASA/JSC and active at Rockwell, was cancelled in early 1982, since the high altitude insertion (to about 300 to 320 nm) does not require the kits. But the most important factor affecting TMS was the announced doubling of STS launch costs, to take effect in late 1985.

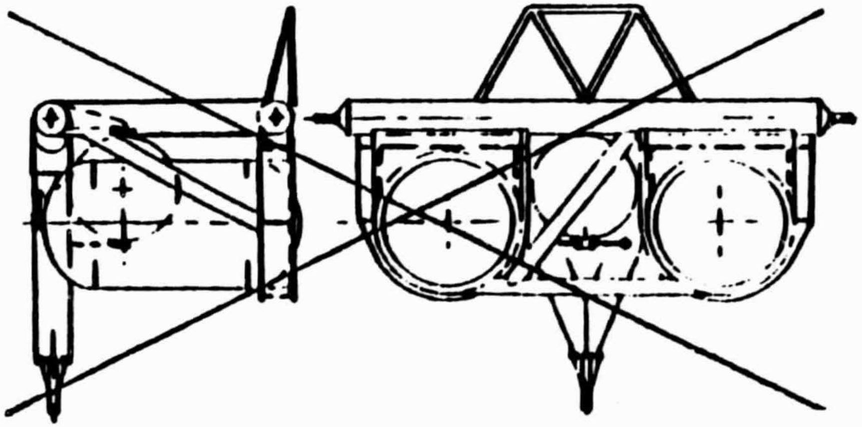
TMS BENEFITS ASSESSMENT STUDY
NEW ISSUES

- THREE FACTORS HAVE EMERGED SINCE STUDY BEGAN

✓ ORBITER HIGH ALTITUDE ASCENT WITHOUT OMS KIT

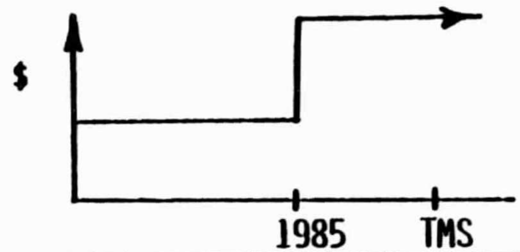


✓ OMS KIT CANCELLED;
NO PLANS TO REINSTATE
- REDUCES ORBITER MISSION OPTIONS
- INCREASES NEED FOR TMS
  - MISSION DIVERSITY/SHARING
  - ORBITER/TMS PARALLEL USE



✓ MORE THAN DOUBLING OF STS LAUNCH PRICES BY LATE 1985

- INCREASES GROUND BASING COSTS
- INCREASES SERVICING BENEFITS



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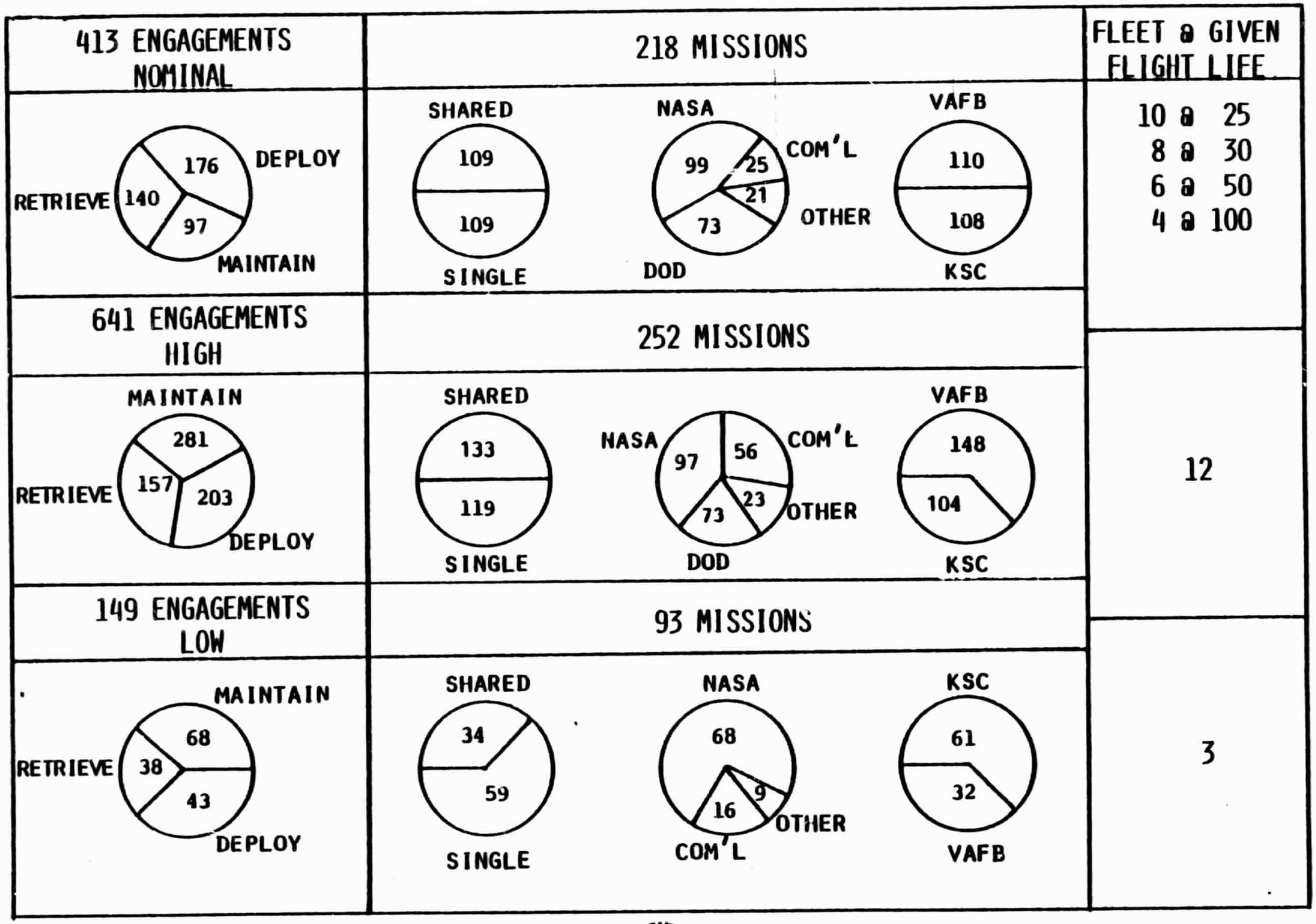
TASK 4.1 - MISSION MODELS, GROUND BASED

Nominal, high, and low mission models were developed for the TMS. All subsequent analyses were based on the nominal model. An engagement is defined as any one of three TMS functions: Deployment, retrieval, or maintenance. For the ground based TMS, a mission is defined as a single STS launch of TMS, which might include one or more TMS payloads in the cargo flight manifest, a single function or engagement, or a sharing in any combination or number of engagements. TMS fleet size was driven by two factors: GEO missions, in which TMS is expended, and ground turnaround time (GTAT). For the nominal model, 8 GEO service missions were identified. A GTAT of 40 days was determined by careful analysis of ground operations. It was found that TMS flight life was dominant in fleet sizing, which for the nominal model was 25 flights, 50 for the low, and 30 for the high. For example, a 30-flight life for the nominal model reduced fleet size from 10 to 8 vehicles; 50 flights, 6 vehicles; and 100 flights, 4 vehicles.

Further analyses late in the study have shown that the 218 launches, in the nominal model can be reduced by 16 launches, to 202 or 194 non-GEO launches. This increase in shared missions produced TMS propulsion benefits over integral spacecraft propulsion.

TMS BENEFITS ASSESSMENT STUDY

TASK 4.1 - MISSION MODELS, GROUND BASED



TASK 4.2 - TMS/PAYLOAD/ORBITER SYSTEMS INTEGRATION

A GTAT of 40 calendar days, including use of weekends only as backup in case of emergencies, is specified. It is also noted that the normal payload integration cycle of 28 months is under intensive study by NASA, with proposed cycles as short as 18 to 10 months showing promise.

- TMS GROUND OPERATIONS

40 DAYS MINIMUM GTAT

TURNAROUND	40 DAYS
REFURBISHMENT	37 DAYS
CONTINGENCY MISSION INTEGRATION	62 DAYS
NORMAL PAYLOAD INTEGRATION	28 MONTHS

- RECURRING INTEGRATION AND DOCUMENTATION

  CONTRIBUTE TO GROUND BASING COSTS

	RECURRING	NON-RECURRING
DOCUMENTS	39	95
PAGES	617	2633
DRAWINGS	20	114

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TMS BENEFITS ASSESSMENT STUDY

TASK 4.3 - COSTING SUMMARY

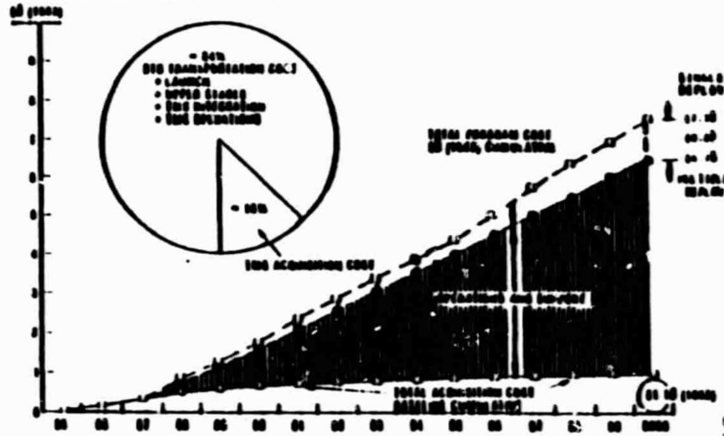
A key objective of the costing analysis was to determine the sensitivity of TMS savings to the required investment of $1.1B, based on a fleet size of 12 flight vehicles. It was found that STS transport costs of $6.4B formed 85% of the combined $7.5B program cost, thus indicating that the 15% investment cost would have but slight effect on TMS benefits, compared with the real driver, transport costs. The effect of these latter costs would provide the key to TMS propulsion use by showing its benefits over integral propulsion for deployment and retrieval of spacecraft, when TMS missions were carefully planned to include multiple engagements and multiple TMS payload manifesting whenever possible.

Sensitivity of TMS benefits to investment cost is further reduced when flight life is extended beyond the 25 flights used in the analysis. At 50 flights, for example, fleet size drops to 6.

TMS BENEFITS ASSESSMENT STUDY

TASK 4.3 - COSTING SUMMARY

$280M TMS PROGRAM SAVING BY MISSION SHARING IS ACHIEVABLE



- BENEFIT/COST OF TMS IS <u>NOT</u> SENSITIVE TO TMS ACQUISITION COSTS
- STS TRANSPORT COSTS DRIVE TOTAL TMS PROGRAM COSTS
- WITH 50% MISSION SHARING AND NO MULTIPLE MANIFESTING: (218 LAUNCHES)

  TOTAL TMS PROGRAM COST $7.5B 82, 1988-2000

✓ TMS ACQUISITION (12 UNITS)	$1.1B
✓ STS TRANSPORT AND TMS FLT OPS	$6.4B
	$7.5B

- WITH ACHIEVABLE MISSION SHARING (202 LAUNCHES):

PROGRAM COST	$7.2B
TRANSPORTATION, FLT OPS	$6.1B

- WITH MAXIMUM MULTIPLE MANIFESTING (GOAL):

PROGRAM COST	$6.7B
TRANSPORT & FLT OPS	$5.6B

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*BASED ON 82 DAYS GTAT AND 25-FLIGHT LIFE, LATER REDUCED TO 10 UNITS AT 40 DAYS GTAT.

TMS VERSUS OMS KITS

Though, in early 1982, with Rockwell under contract to build a two-kit OMS package, it appeared that a serious contender for certain TMS missions was likely to emerge, it was known that TMS would provide a very large launch cost saving over the kits and that their use would generally be justified only for contingency missions requiring man's presence (even here, a manned TMS was seen as an eventuality). This, coupled with its subsequent cancellation, relegated TMS/kit trade studies to lower priority, especially since there are no current plans for further kit development.

The price shown for the flight unit included profit. Since WTR had scheduled several OMS kit missions, a composite Orbiter payload capacity of 48,500 pounds was used in estimating launch costs. A dedicated launch price of $71M in 1982 dollars was assumed.

SPACE SHUTTLE ORBITER

TMS BENEFITS ASSESSMENT STUDY

TMS VERSUS OMS KITS

- FULL PERFORMANCE TMS: AN STS BENEFITS/COST BARGAIN

  ✓ ADDED BENEFITS - REMOTE SERVICING; OUTPERFORMS OMS KIT

  ✓ REDUCED COSTS - FEWER ORBITER BASED OPERATIONS

  - TMS LAUNCH COST @ 8770 LB: $17.1M
    (ETR/WTR COMPOSITE 48,500 LB CAPACITY)

  - 2 OMS KITS DDT&E, ONE FLIGHT UNIT: $23.75M

  - OMS KIT LAUNCH COST (ETR/WTR COMPOSITE):

    1 KIT @ 19493 LB: $38M̄; 2 KITS @ 32738 LB: $64M̄

TMS BENEFITS ASSESSMENT STUDY

TASK 4.4 - TMS BENEFITS SUMMARY

The TMS benefits study emphasized three areas of economic analysis: Comparisons with integral spacecraft propulsion, spacecraft remote servicing, and program profitability. The results are summarized as follows:

- TMS saves $170\bar{M}$ over integral propulsion. Maximum (goal):$\$700\bar{M}$.
- TMS remote servicing saves $\$3.4\bar{B}$, based on low user acceptance.
- TMS would break even as early as 4 years after IOC, by efficient utilization of mission sharing.
- Internal Rate of Return on investment is an exceptional 28%.

TMS BENEFITS ASSESSMENT STUDY

TASK 4.4 - TMS BENEFITS SUMMARY

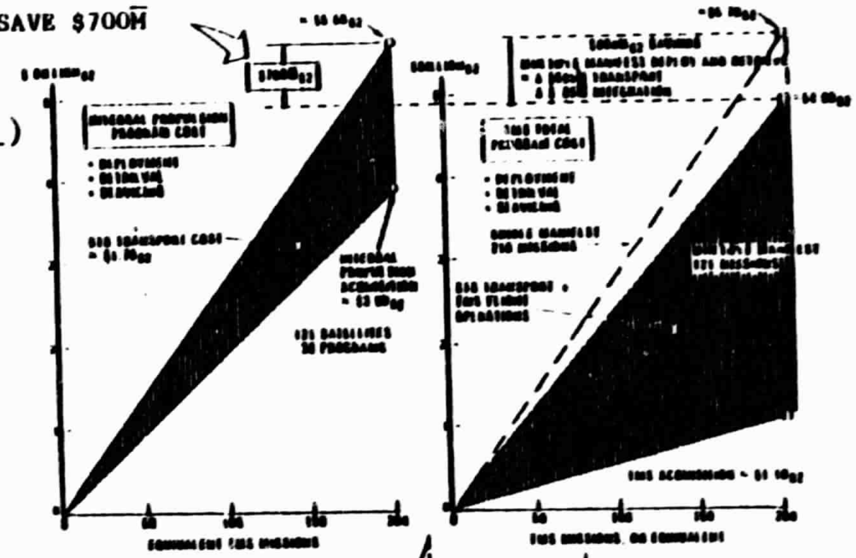
GOAL FOR TMS: SAVE $700\bar{M}$

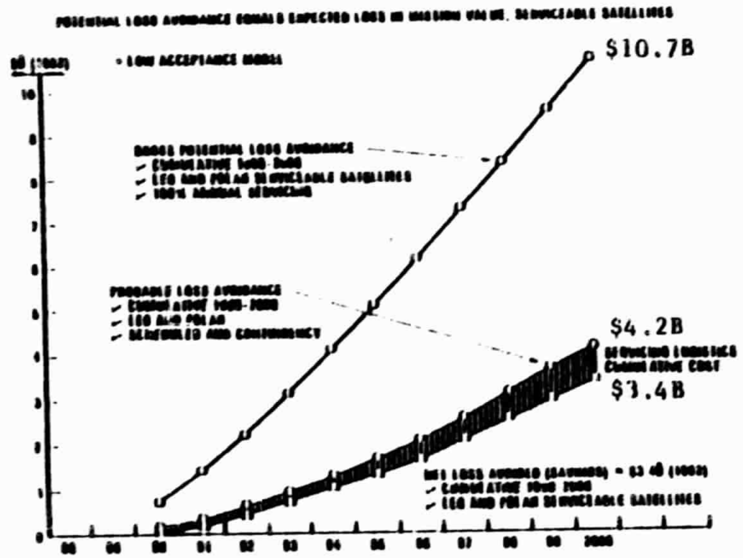
TMS NET BENEFITS:

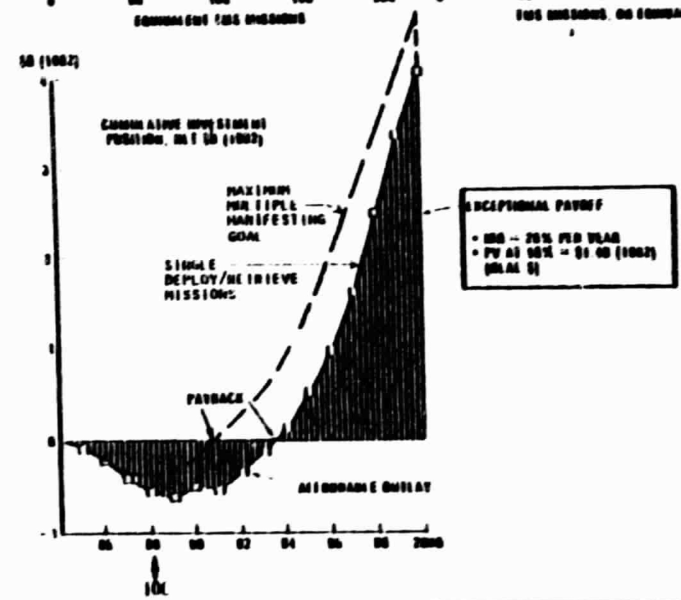
- PROPULSION: $170\bar{M}$ ($700\bar{M}$ MAX IS GOAL)
- SERVICING: $3.4\bar{B}$
- PAYBACK: 4 YEARS FROM IOC
- PROFITABILITY: 28% IRR

✓ OTHER QUALITATIVE VALUES ADDITIVE

- GROUND BASED TMS BENEFITS DRIVEN BY TRANSPORT COSTS







TMS BENEFITS ASSESSMENT STUDY
SPECIAL INTEREST STUDY TASKS

- $\boxed{\text{TMS REMOTE MAINTENANCE VERSUS ORBITER/EVA}}$
- TMS BENEFITS SENSITIVITY TO INCREASES IN LAUNCH CHARGES
- TMS VERSUS INTEGRAL PROPULSION - ADDITIONAL POTENTIAL SAVINGS FOR TMS
  - TMS WEIGHT REDUCTIONS
  - TMS LENGTH PENALTY REDUCTIONS
  - INTEGRAL PROPULSION LENGTH PENALTIES
  - TMS VERSUS INTEGRAL PROPULSION VERSUS SPACECRAFT SIZE
- TMS BASING MODES ANALYSIS

TMS VERSUS INTEGRAL PROPULSION, REMOTE VERSUS EVA SERVICING

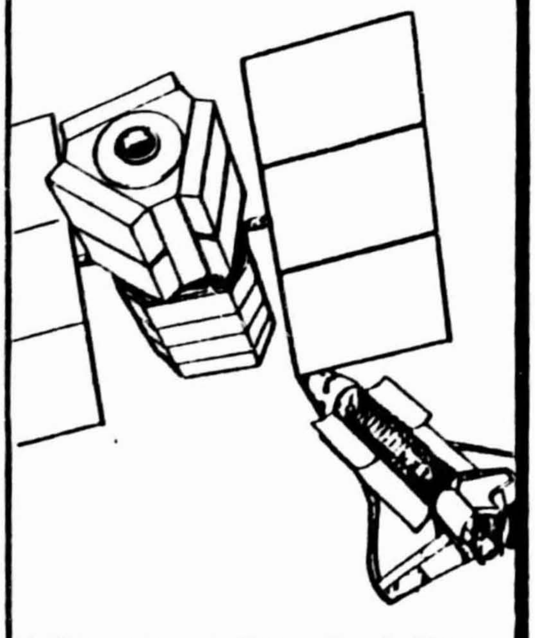
TMS REMOTE SERVICING SAVES OVER $10M̄/MISSION OR 38%

This special task evaluated another aspect of the TMS comparison with integral propulsion - their effect on spacecraft maintenance economic benefits. Three scenarios were identified. Integral propulsion has no options. The spacecraft must return to the Orbiter for servicing, assumed to be EVA. The TMS, however, may retrieve the spacecraft for EVA aboard the Orbiter, or perform remote servicing. It was found that the servicing mode affected spacecraft delivery costs, as well as servicing, so both missions are shown. Only delta costs affecting the cost comparison are considered. For example, spacecraft launch costs are not given, except for integral propulsion delta costs. Among many conservative assumptions, length penalties for the length driven delivery launches were not assessed against integral propulsion. Reason for the slightly higher cost of the integral propulsion delivery was the obvious penalty which limits hardware use to a single spacecraft. For the service missions, the key cost element was the ASE required in the Orbiter payload bay, followed by costs related to EVA servicing. Principal reason for the high cost of the TMS/EVA option was the launch weight which included all equipment used in the other two scenarios. Note that savings accelerate when a second service mission is added, at a total TMS saving of $19.4.

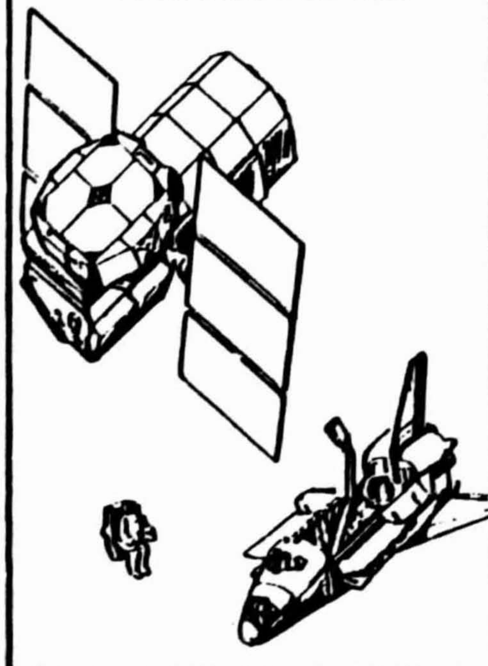
TMS BENEFITS ASSESSMENT STUDY

TMS VERSUS INTEGRAL PROPULSION, REMOTE VS EVA SERVICING

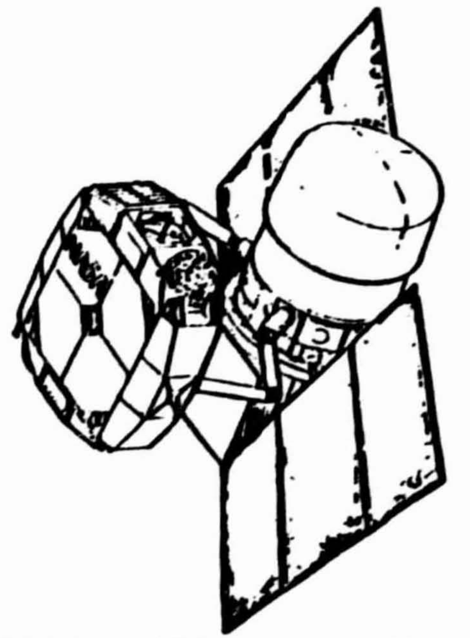
RETURN FOR EVA



RETRIEVE FOR EVA



REMOTE SERVICE



COST ELEMENT	INTEGRAL PROPULSION	TMS - GROUND BASED	
	RETURN FOR EVA	RETRIEVE FOR EVA	REMOTE SERVICE
MISSION 1 - DELIVERY	11.4M	10.4M	10.4M
MISSION 2 - MAINTENANCE	27.6M	44.3M	18.4M
TOTALS			
1 DELIVERY, 1 MAINTENANCE	39.0M	54.7M	28.[illegible]M
1 DELIVERY, 2 MAINTENANCE	66.6M	99.0M	47.2M

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TMS VERSUS INTEGRAL PROPULSION, REMOTE VERSUS EVA SERVICING

The data shown expand on that given in the prior summary chart. Launch costs were based on a full performance Orbiter at 28.5^{0} orbit inclination. For the PMII propulsion module used in the analysis, the DDT&E Battelle/Vought value, escalated to 1982 dollars, was conservatively spread over four satellites. Even more conservative was the costing of a servicer for each of the TMS vehicles in the fleet. The initial fleet size of 12 vehicles/servicers, 8 of which are lost at GEO, was reduced to 10, allowing a conservatively adjusted acquisition cost of \$965M, down from \$1.1B, as a result of reducing GTAT from 82 to 40 days. Spreading this cost over 413 engagements yields the \$2.3M value shown. Note that this is doubled for the TMS retrieval scenario since both retrieval and redeployment are required. TMS dry weight was 3770 pounds (112, 281, and 2545 for AFD equipment, docking kit, and TMS, respectively), plus 1301 pounds of fuel for the remote maintenance mission, and 2426 pounds for the retrieval/deployment required in the TMS/EVA scenario. Servicer weight and replacement modules were set at 600 and 2900 pounds, respectively. Cradle weight was 832 pounds.

EVA related costs were obtained from the NASA "Payload Integration Plan" (PIP) for both the Multimission Modular Spacecraft (MMS) and the Space Telescope (ST). A careful effort was made to extract for use only those costs representative of expected maintenance missions. For example, costs of the environmental protection enclosure, and the gaseous nitrogen kit required for the ST, were not included, nor were costs recovered for development of a fully automated module exchange mechanism for the Flight Support Station (FSS) of the MMS, which is not presently planned for use. Cargo weight of the FSS was set at 10,000 pounds, plus 800 for the module carrier.

For the TMS/EVA scenario, total cargo weight was 20728 pounds, and for TMS remote maintenance, 9403 pounds.

TMS BENEFITS ASSESSMENT STUDY

TMS VERSUS INTEGRAL PROPULSION - REMOTE VERSUS EVA SERVICING

COST ELEMENT	INTEGRAL PROPULSION	TMS - GROUND BASED	
	RETURN FOR EVA	RETRIEVE FOR EVA	REMOTE SERVICE
1st MISSION - DELIVERY, LENGTH DRIVEN, 28.5°	(\$11.4M)	(\$10.4M)	(\$10.4M)
• TMS LAUNCH	-	5.7	5.7
DDT&E + HARDWARE	-	2.3	2.3
• PMII MODULE + SPACECRAFT INTEG.	6.2 16/4 = 4.0	-	-
• ORBITER INTEGRATION	1.2	2.4	2.4
2nd MISSION - MAINTENANCE, WEIGHT DRIVEN, 28.5°	(\$27.6M) FSS + MODULES	(\$43.1M) TMS/FSS/MODULES	(\$17.2M) TMS/SERVICER/MOD
• LAUNCH	18.5	29.0	12.5
DDT&E +	1.0	4.6	2.3
HARDWARE	1.0	2 TMS TRIPS	413 ENGAGEMENTS
• EVA + EQUIPMENT	0.8 + 0.2 = 1.0	1.0	TMS FLEET SIZE: 10
RENDEZ/PROXIM OPS	0.4	0.4	
ORBITER/RMS SIMULAT.	0.3 = 1.3	0.3	
ORBITER EXTRA DAY	0.6	0.6	
• ORBITER INTEGRATION	4.8	7.2	2.4
• TOTALS: 1 DELIVERY, 1 MAINT.	\$39.0M	\$53.5M	\$27.6M
1 DELIVERY, 2 MAINT.	66.6	96.6	44.8

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TMS BENEFITS ASSESSMENT STUDY

EVA CONSIDERATIONS (VERSUS TMS REMOTE SERVICING)

These data were extracted from the NASA/JSC Payload Integration Plan documents for the Multimission Modular Spacecraft (JSC 14082) and Space Telescope (JSC 14009), which covered the delivery and on orbit maintenance missions, and the retrieve to ground mission. It was decided that only those costs representative of general maintenance missions would be included. All of the special purpose ASE for the Space Telescope was excluded, such as the environmental protection enclosure. For the MMS, a non-escalated cost recovery of $1M per mission was assumed, based on data obtained from the Program Manager for development of the Flight Support System (FSS) maintenance hardware. Additionally, no penalties were assessed against the FSS for recovery of costs to develop automated servicer hardware. Furthermore, the backup EVA costs shown were not included in the TMS/EVA trade analysis. These are considered conservative assumptions, placing EVA mission costs on the low side of expected actual costs.

An EVA is normally defined as 2 crewmen for 6 hours.

TMS BENEFITS ASSESSMENT STUDY
EVA CONSIDERATIONS (VERSUS TMS REMOTE SERVICING)

- ORBITER BASELINE EVA PROVISIONS (2 MEN PER 6 HOUR EVA)
  - ✓ 3 EVA'S: 2 FOR PAYLOAD SUPPORT; 1 FOR ORBITER CONTINGENCY
  - ✓ EVA PRICING GUIDELINE FLOOR ('82 $): $0.116M TO $0.194M
- EVA COSTS, INCLUDING TRAINING: (MAINTENANCE SHOWN; REPAIR HIGHER)

✓ SPACE TELESCOPE (PARTIAL SUMMARY)		✓ MULTIMISSION MODULAR SPACECRAFT	
- DELIVERY (2 BACKUP EVA'S)	$0.767M	- RETRIEVAL (2 BACKUP EVA'S)	$0.767M
EVA EQUIPMENT	0.219	EVA EQUIPMENT	0.219
	$0.986M		$0.986M
- MAINTENANCE (3 EVA'S)	1.151	- MAINTENANCE (2 EVA'S)	0.767
EVA EQUIPMENT	>4.000	EVA EQUIPMENT	> 1.219
EXTRA DAY ON ORBIT	0.581	EXTRA DAY ON ORBIT	0.581
	$5.732M		$2.567M
BACKUP EVA	$0.384M	BACKUP EVA'S	$0.767M
- RETURN (2 BACKUP EVA'S)	0.767	- RETURN (2 BACKUP EVA'S)	0.767
EVA EQUIPMENT	~0.219	EVA EQUIPMENT	0.219
	$0.986M		$0.986M
TOTAL: $5.732M TO $8.088M		TOTAL: $2.567M TO $5.306M	

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TMS BENEFITS ASSESSMENT STUDY
SPECIAL INTEREST STUDY TASKS

- TMS REMOTE MAINTENANCE VERSUS ORBITER/EVA
- TMS BENEFITS SENSITIVITY TO INCREASES IN LAUNCH CHARGES
- TMS VERSUS INTEGRAL PROPULSION -
  ADDITIONAL POTENTIAL SAVINGS FOR TMS
  - TMS WEIGHT REDUCTIONS
  - TMS LENGTH PENALTY REDUCTIONS
  - INTEGRAL PROPULSION LENGTH PENALTIES
  - TMS VERSUS INTEGRAL PROPULSION VERSUS SPACECRAFT SIZE
- TMS BASING MODES ANALYSIS

TMS BENEFITS ASSESSMENT STUDY

TMS SERVICING BENEFITS INCREASE AS LAUNCH CHARGES INCREASE

The TMS, servicer, and ASE are 5700 pounds lighter than the 10,800 pounds of ASE required for Orbiter/EVA servicing, which is based on the Multimission Modular Spacecraft support equipment. Based on NASA estimates of potential launch costs in 1988, and assuming user charges will match costs, delta launch charges at ETR and WTR can be derived, as shown in the chart. These are readily converted to payload user charges.

TOTAL PROGRAM SAVINGS FOR TMS: $659M

TMS BENEFITS ASSESSMENT STUDY
TMS SERVICING BENEFITS INCREASE AS LAUNCH CHARGES INCREASE

- DATA
  - TMS 5700 LB LIGHTER THAN ASE FOR ORBITER/EVA SERVICING
  - LAUNCH CHARGE FOR 1985 - 1988: 70.8\bar{M}$, ETR AND WTR
  - POTENTIAL CHARGES IN 1988: 92\bar{M}$ AT ETR, 122\bar{M}$ AT WTR
  - APPROXIMATELY 45 MISSIONS EACH AT ETR AND WTR
  - DELTA LAUNCH CHARGE: 21.2\bar{M}$ AT ETR, 51.2\bar{M}$ AT WTR

- ANALYSIS

  ETR: | 5700/(65000 X 0.75) | 21.2 X 45 = 112\bar{M}$

  WTR: | 5700/(32000 X 0.75) | 51.2 X 45 = 547\bar{M}$

- TOTAL TMS BENEFIT $\boxed{\$659\bar{M}}$

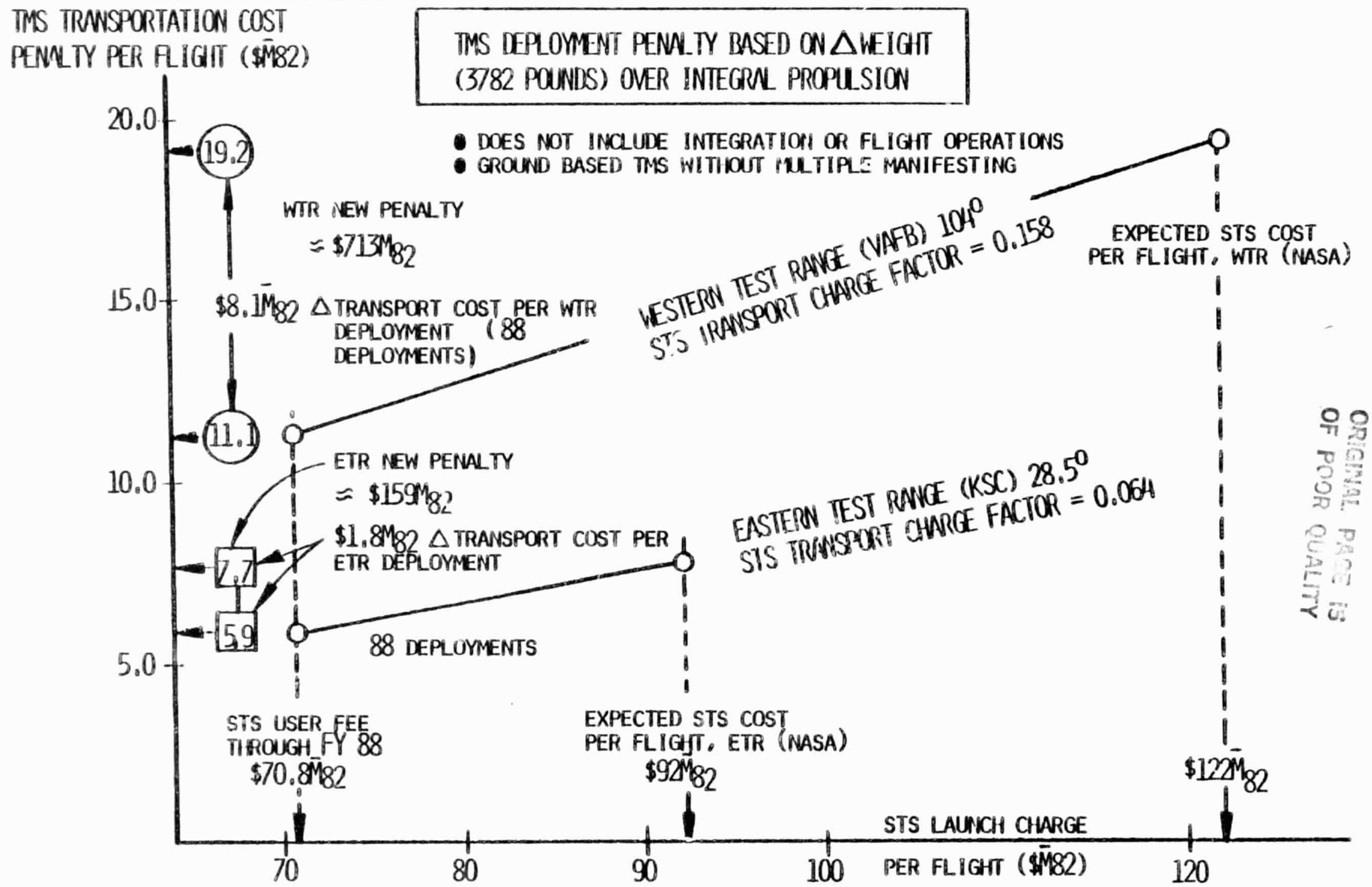
TMS BENEFITS ASSESSMENT STUDY

TMS DEPLOYMENT SENSITIVITY TO INCREASES IN STS LAUNCH CHARGES

TMS propulsion saves \$170M over integral propulsion, based on 202 launches, and program costs drop \$270M. These savings are based on recently announced launch charges, effective in late 1985 through 1988. Should the charges rise to match estimated costs, the result would be shown in the chart. New program costs of \$872M would accrue, based on 50% shared missions and single manifesting of deployment payloads.

However, the \$270M program cost avoidance was based on multiple engagements and single manifesting. If the minimum of only two payloads were co-manifested, with launch charges shared equally, the \$872M penalty from increased launch charges drops by half to \$436M. The effect of this reduced penalty of the \$270M program saving is to reduce it to a net loss of \$166M. Increasing multiple manifesting to more than two payloads per STS launch will further reduce penalties.

TMS DEPLOYMENT BENEFITS DIMINISH AT EXPECTED STS COSTS



TMS BENEFITS ASSESSMENT STUDY

SPECIAL INTEREST STUDY TASKS

- TMS REMOTE MAINTENANCE VERSUS ORBITER/EVA
- TMS BENEFITS SENSITIVITY TO INCREASES IN LAUNCH CHARGES
- TMS VERSUS INTEGRAL PROPULSION - ADDITIONAL POTENTIAL SAVINGS FOR TMS
    - TMS WEIGHT REDUCTIONS
    - TMS LENGTH PENALTY REDUCTIONS
    - INTEGRAL PROPULSION LENGTH PENALTIES
    - TMS VERSUS INTEGRAL PROPULSION VERSUS SPACECRAFT SIZE
- TMS BASING MODES ANALYSIS

TMS BENEFITS ASSESSMENT STUDY

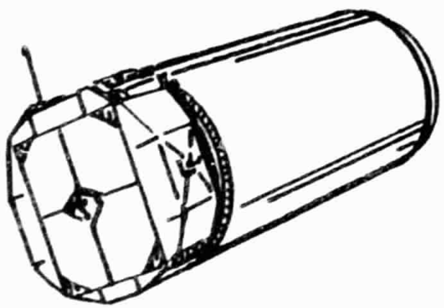
TMS VERSUS INTEGRAL PROPULSION

This special task was undertaken as part of an inhouse effort to further enhance TMS performance as a propulsion stage, whether operating in the ground based or space based mode. In addition to the benefits of shared missions, this task evaluated the potential of space basing, plus weight reduction, which benefits either basing mode, and effective reductions in TMS length, aimed primarily at lowering transport costs of the ground based TMS in length driven launches.

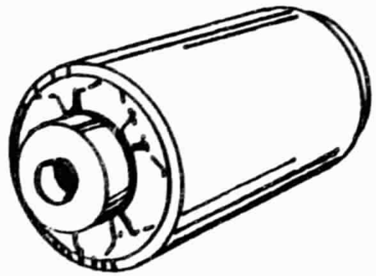
TMS BENEFITS ASSESSMENT STUDY
TMS VERSUS INTEGRAL PROPULSION

FACTORS:
- MISSION SHARING
- PROPULSION COST
- TRANSPORTATION COST
- OPERATING MODE

TMS



INTEGRAL PROPULSION



SOLUTION:
- MULTIPLE MANIFESTING
- REDUCE WEIGHT/LENGTH OF TMS
- IDENTIFY INTEGRAL PROPULSION LENGTH PENALTIES
- SPACE BASING

TMS VERSUS INTEGRAL PROPULSION - WEIGHT REDUCTIONS

POTENTIAL PROGRAM SAVINGS OF $359M̄

Two potential weight reduction measures were evaluated, both of which are under study by Vought. A switch from the baseline monopropellant to bipropellant would save over 1300 pounds in fuel weight. Elimination of the ASE cradle saves about 550 pounds (present weight is about 600, plus 230 pounds of black boxes). Basic structure could then be lightened, for a potential total reduction approaching 2000 pounds. Translated to launch cost savings, a program cost reduction of approximately $360M̄ is realized.

TMS VERSUS INTEGRAL PROPULSION, WEIGHT REDUCTIONS

EFFECT OF POTENTIAL WEIGHT REDUCTIONS ON GROUND BASED TMS TRANSPORT COST

POTENTIAL WEIGHT REDUCTIONS	SAVINGS (LBS)
USE BIPROPELLANT FUEL	> 1300
DELETE CRADLE	550
RESULTING LIGHTER STRUCTURE	150
TOTAL WEIGHT SAVINGS	2000

WEIGHT DRIVEN LAUNCHES	COST SAVINGS ($)
44 AT WESTERN TEST RANGE @ \$5.92M/LAUNCH	260.5M
34 AT EASTERN TEST RANGE @ \$2.91M/LAUNCH	98.9M
TOTAL POTENTIAL TRANSPORT COST SAVINGS	359.4M

TMS VERSUS INTEGRAL PROPULSION - LENGTH REDUCTIONS

ANNULAR TMS POTENTIAL PROGRAM SAVINGS: $\$181\bar{M}$

An annular TMS concept featuring a large central cavity into which payloads could be inserted, would, for length driven missions, reduce TMS launch costs from its present $\$5.65\bar{M}$ to zero. As a conservative assumption that precluded payload redesign, only those presently below 9.8 feet in diameter were included. It is noted that if all payloads become Shuttle optimized, i.e., full diameter, at a linear density of 1083 lb/ft at ETR, 28.5^{o}, the TMS maximum effective length charge of $\$2.37\bar{M}$ is based on one-half its full length, or approximately 1.5 feet. Assuming these redesigned payloads can take advantage of the TMS by providing a 9.8 foot diameter X 3 foot long shoulder, all 63 length driven payloads in the nominal model would avoid $\$149\bar{M}$ in transport costs. This TMS configuration would encourage ground mating with the payload, something the users have preferred. It could also reduce cantilever load levels.

A number of other potential uses for the central cavity have been identified. While the first two shown may be most obvious and of near term value, the remaining three could prove most advantageous. A problem area is how payload retrieval would be achieved on a deploy/retrieve mission. Side docking with the TMS would preclude need for deploying a cumbersome and complex central docking probe, but may raise other problems looking for solutions. So - though the annular concept is intriguing, it requires considerable additional study.

THE ANNULAR TMS CONCEPT REDUCES LENGTH DRIVEN TRANSPORT COSTS

- CENTRAL CAVITY : 9.83 FT. DIAMETER

  ✓ USES:
  - ADD FUEL TANKS
  - MISSION KITS (SERVICER, ETC)
  - ACCESS BOTH ENDS OF P/L
  - MANNED MODULE
  - NEW STRUCTURES ASSEMBLY OPTIONS

- 63 LENGTH DRIVEN DELIVERY MISSIONS

  32 WITH PAYLOADS LESS THAN 9.83 FT. DIAMETER

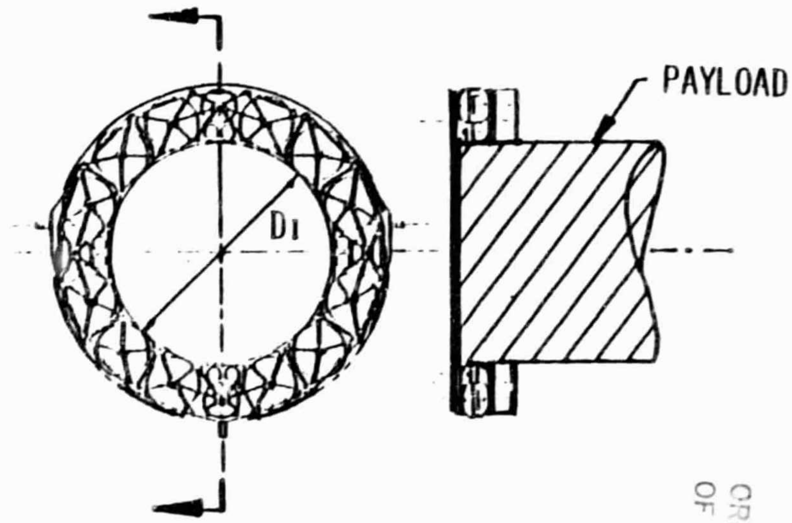
  NO DoD, GEO, MAINTENANCE, OR RETRIEVAL

- ZERO TMS TRANSPORT COST FOR 32 MISSIONS

  ✓ SAVINGS: \$5.65M X 32 = $\boxed{\$180.8M}$

- SAVINGS DIMINISH FOR SHUTTLE OPTIMIZED (FULL DIAMETER) PAYLOADS: TMS ADDS 1.5 FEET TO PAYLOAD LENGTH

  FAR TERM SAVINGS: \$2.37 X 63 = \$149.3M



ANNULAR TMS CONCEPT
L = 36" TO 42"
D_O = 14.5'
D_I = 9.8'
W_P = 3700 LB

INTEGRAL PROPULSION LENGTH DRIVEN LAUNCH COST ANALYSIS

INTEGRAL PROPULSION LENGTH PENALTIES OF $69\bar{M}$ TO $171\bar{M}$ ARE TMS BENEFITS

In studies conducted by Battelle Laboratories, the assumption was made that integral spacecraft propulsion systems, when buried inside the spacecraft, did not add length. This assumption was also used by Vought. A special task was initiated which assumed that any new volume required within the spacecraft for integral propulsion must, if diameter were held constant, increase its length. All length driven spacecraft and their appropriate integral propulsion modules (as used by Battelle) were identified and module volumes converted to delta spacecraft lengths, which ranged from 0.5 to 2.2 feet (except for one Landsat mission known to use a PMII module attached to the MMS bus). A second analysis assumed maximum penalties by adding the full module length to the spacecraft. Finally, a third assumption that WTR launch costs would exceed the $71\bar{M}$ ETR price by 50% was included, thus generating a total of four program launch cost penalties for the different options. These ranged from a minimum of $69\bar{M}$ to a maximum of $171\bar{M}$. The smaller cost was conservatively assumed for subsequent analysis, with actual costs lying between the extremes. This integral propulsion cost penalty was treated as a TMS benefit.

TMS BENEFITS ASSESSMENT STUDY

INTEGRAL PROPULSION LENGTH DRIVEN LAUNCH COST ANALYSIS

SPACECRAFT	NO. MISSION	PM NO.	PAYLOAD ΔL_{MIN} FT.	TOTAL LAUNCH COST (MIN.)	PAYLOAD ΔL_{MAX} FT.	TOTAL LAUNCH COST (MAX.)
ETR						
XTE	1	I	0.5	0.9	1.3	2.1
SCE	1	I	1.0	1.5	5	7.9
XSE	1	II	2.2	3.5	5	7.9
MLSE	1	II	0.7	1.1	5	7.9
EUVSE	1	II	1.0	1.5	5	7.9
UARS	2	II	1.1	3.5	5	15.8
TOPEX	4	I	0.2	1.5	1.3	8.4
ERBS	1	II	2.0	3.1	5	7.9
SSM	2	II	0.4	14.1	5	15.8
LARS	3	I-B	0.4	1.8	2.7	12.6
WTR						
GP - B	1	II	0.5	.8, 1.2	5	7.9, 11.9
LANT	4	II	5	31.6, 47.3	5	31.6, 47.3
MFS	2	I	0.3	1.1, 1.6	1.3	4.2, 6.3
ATM	1	II	2.2	3.4, 5.2	5	7.9, 11.9
	25	71 M̄/LAUNCH, ETR/WTR: 106.5 M̄/LAUNCH, WTR:		69.4 87.9		145.7 171.4

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INTEGRAL PROPULSION LENGTH DRIVEN LAUNCH COST ANALYSIS (contd.)

This chart expands the data summarized in the prior chart, showing the steps in developing the analysis. To enable direct evaluation of the Battelle assumption that integral propulsion, buried in the spacecraft, would add no length, the same modules, including size and volume, are used here. Only one spacecraft, Landsat, was excepted from the assumption of a buried module, since it used the MMS bus. It is noted that Landsat uses a PM-I propulsion module for ELV ground launch. The module provides for only a one-way trip to the Orbiter for retrieval. For ground launch aboard the Orbiter, however, the larger PM-II module is required for the round trip deployment and return to the Orbiter for retrieval.

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TMS BENEFITS ASSESSMENT STUDY
INTEGRAL PROPULSION LENGTH DRIVEN LAUNCH COST ANALYSIS

SPACE CRAFT	NO. MISS.	PM NO.	PM VOL. FT^3	P/L AREA FT^2	P/L ΔL_{MIN} FT	LAUNCH COST $\bar{M}, '82	TOTAL LAUNCH COST (MIN.)	P/L ΔL_{MAX} FT	LAUNCH COST $\bar{M}, '82	TOTAL LAUNCH COST (MAX.)
ETR:										
XTE	1	I	18.18	33.18	0.548	0.865	0.865	1.33	2.098	2.098
SCE	1	II	73.74	75.43	0.978	1.543	1.543	5	7.889	7.889
XSE	1	II	73.74	33.18	2.22	3.503	3.503	5	7.889	7.889
MLSE	1	II	73.74	103.87	0.710	1.120	1.120	5	7.889	7.889
EUVSE	1	II	73.74	75.43	0.978	1.543	1.543	5	7.889	7.889
UARS	2	II	73.74	66.48	1.109	1.750	3.500	5	7.889	15.778
TOPEX	4	I	18.18	75.43	0.241	0.380	1.520	1.33	2.098	8.392
ERBS	1	II	73.74	37.39	1.972	3.111	3.111	5	7.889	7.889
SSM	2	II	73.74	165.13	0.447	7.053	14.106	5	7.889	15.778
LARS	3	I-B	36.36	97.64	0.372	0.587	1.761	2.67	4.213	12.639
WTR:						(1,1.5 ETR)			(1,1.5 ETR)	
GP-B	1	II	73.74	149.57	0.493	.78, 1.17	.78, 1.17	5	7.89, 11.83	7.89, 11.83
LANDSAT	4	II	73.74	-	5	7.89, 11.83	31.56, 47.34	5	7.89, 11.83	31.56, 47.34
MFS	2	I	18.18	52.81	0.344	.54, .82	1.09, 1.63	1.33	2.10, 3.15	4.20, 6.29
ATM	1	II	73.74	33.80	2.182	3.44, 5.17	3.44, 5.17	5	7.89, 11.83	7.89, 11.83
	25	$71M̄/LAUNCH, ETR/WTR: $106.5M/LAUNCH, WTR:					9.442, [illegible].882			145.660, 171.428

Space Transportation System
Development & Production Division
Space Systems Group

Rockwell International

TMS VERSUS INTEGRAL PROPULSION - SUMMARY

TMS PROVIDES A 3 TO 14% SAVING

By summing the total potential benefits of TMS, including mission sharing (3% @ \$170M) and weight/length reductions (11% @ \$610M), a total of \$780M is potentially obtainable. If the annular TMS is excluded, the range becomes 3 to 12%.

SUMMARY COMPARISONS: $\boxed{\text{GROUND BASED TMS}}$

- BASELINE CONFIGURATION REDUCES PROPULSION COSTS FROM 5.6B_{82}$ (USING INTEGRAL PROPULSION) TO <u>$5.4</u>$B_{82}$ FOR TMS ($170M SAVING)=<u>3%</u>
- ADDITIONAL TMS COST SAVINGS COMPARED TO INTEGRAL PROPULSION

WEIGHT REDUCTION	359.4\bar{M}_{82}$
ANNULAR TMS	180.8
INTEGRAL PROPULSION (LENGTH EFFECT)	69.4
	$\boxed{\$609.6\bar{M}_{82}}$ = <u>11%</u>

- NET RESULT: $\boxed{\text{TMS SHOWS 3 To 14\% COST ADVANTAGE OVER INTEGRAL PROPULSION.}}$

TMS VERSUS INTEGRAL PROPULSION VERSUS SPACECRAFT SIZE

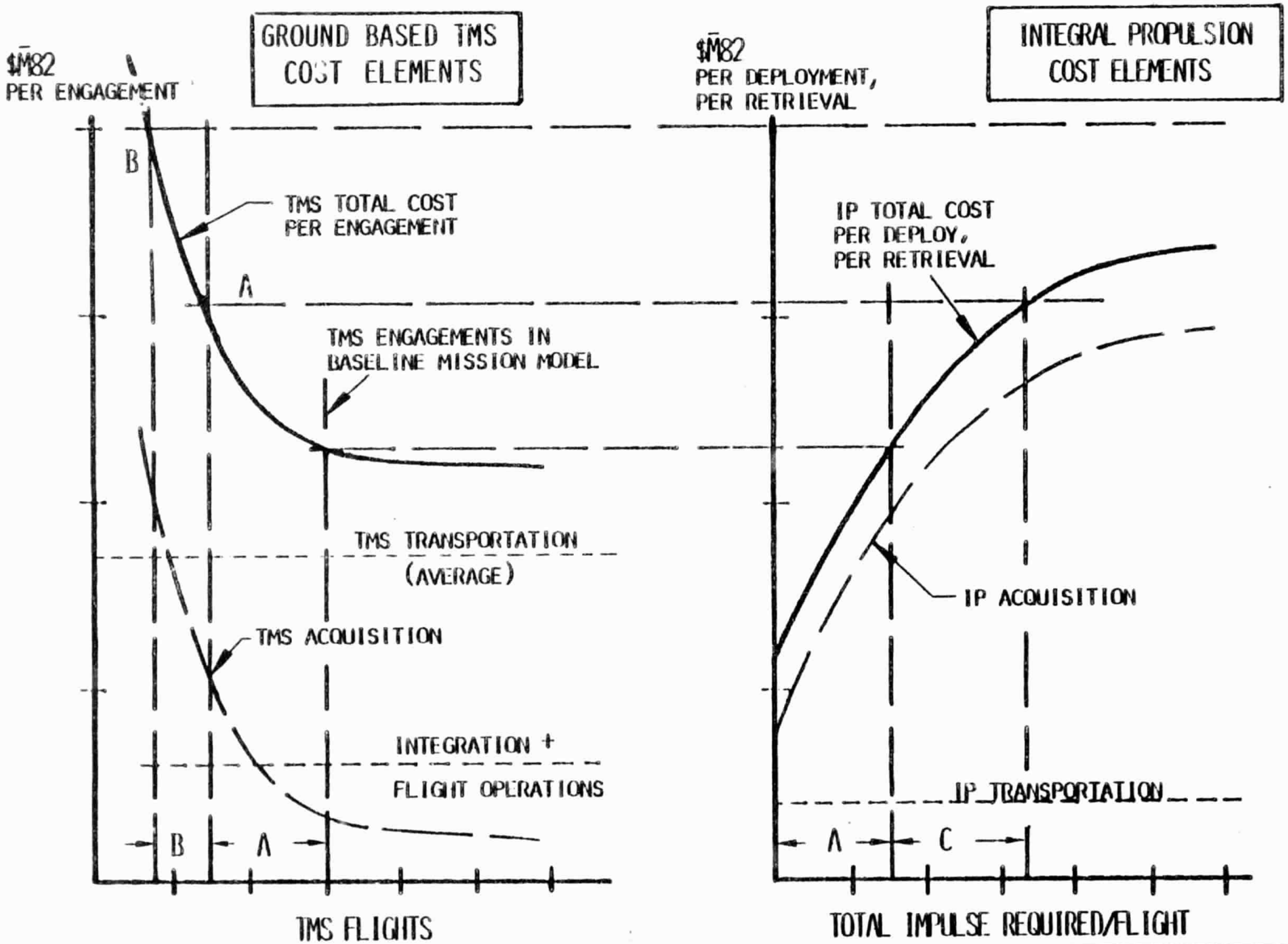
An investigation was made of the possibility that the larger, heavier TMS was unfairly specified as a propulsion system for smaller payloads which used only a small part of TMS capability, resulting in severe off-loading of propellant and sharply reducing stage mass fraction and efficiency. The chart shows the results of the analysis. The striking difference in the curve shapes giving cost per engagement for the two propulsion systems is key to the results. Three vertical lines in the TMS figure represent, from right to left, the baseline engagements and two progressive reductions, as satellites are converted from TMS to integral propulsion and drop out of the TMS mission model. The vertical lines are projected horizontally from their intersect with the TMS curve, to the integral propulsion, then vertically, to show total impulse per flight.

The procedure for using the curves begins with inspection of the integral propulsion curve, where the baseline intersect defines flights in region "A" as being lower in cost than TMS. The "A" flights are then dropped from the TMS model as shown, increasing TMS cost per flight. Projecting horizontally from intersect "A" produces a new intersect for integral propulsion, defining a still larger zone, A+C, in which flight cost is lower than TMS. The cycle is repeated once more. However, decrementing TMS by "C" would have dropped all flights, so a smaller decrement "B" indicates integral propulsion is less costly for any number of missions, regardless of impulse required.

The analysis is based on single manifesting. The effect of increased mission sharing or multiple manifesting of deployment payloads is to produce a TMS benefit which will lower the TMS curve. But the trends remain the same: Diminishing the TMS flight base will raise cost per flight and will erode TMS propulsion benefits.

The implication is clear. Maintaining the TMS flight base is of little concern to the small payload user who will decide between TMS and integral propulsion on economic issues alone. The analysis indicates a cascading effect detrimental to the ground based TMS. There are, however, two potential solutions. Reduce the size of the TMS or alter the basing mode. Potential methods for implementing both solutions are suggested in this benefits study.

THE "OPTIMAL" INTEGRAL PROPULSION DILEMMA



SPACE BASING THE TMS INCREASES BENEFITS

Since STS transport costs drive benefits for the ground based TMS, accounting for over 80% of program costs, an analysis of the potential benefits of space basing as a means of reducing transport costs was undertaken. Only delta costs affecting the basing mode were considered. A reference baseline was developed for the ground based TMS for comparison with two approaches to space basing: One with ground refueling, and the other with on orbit refueling.

TMS BENEFITS ASSESSMENT STUDY
SPECIAL INTEREST STUDY TASKS

- TMS REMOTE MAINTENANCE VERSUS ORBITER/EVA
- TMS BENEFITS SENSITIVITY TO INCREASES IN LAUNCH CHARGES
- TMS VERSUS INTEGRAL PROPULSION - ADDITIONAL POTENTIAL SAVINGS FOR TMS
  - TMS WEIGHT REDUCTIONS
  - TMS LENGTH PENALTY REDUCTIONS
  - INTEGRAL PROPULSION LENGTH PENALTIES
  - TMS VERSUS INTEGRAL PROPULSION VERSUS SPACECRAFT SIZE
- TMS BASING MODES ANALYSIS

EARLY SPACE BASING

In order to take early advantage of the space based TMS benefit potential, a scenario was developed which assumed that neither a space station nor on orbit refueling was required. TMS would be a free flyer between engagements and would be returned to ground for refueling. It was decided to retain the basic TMS configuration, but add a tank module to increase on orbit staytime. An analysis was then performed to size the add-on tank module for optimum economic benefits.

It was seen that the add-on tank module, assumed to be composed of OMS propellant tanks, could also be used for other purposes. A two or four-tank module could serve as one or two OMS kits in the Orbiter payload bay. Use of bipropellant was assumed for all space basing analyses. Four tanks, at 24,000 pounds of propellant, plus 5,000 in the TMS, would allow payload delivery to a 12-hour orbit or to GEO, if the vehicle is expended. Payload to the 12-hour orbit (10,900 nm) is 7,300 pounds, and for the GEO mission, 4,970 pounds. Use of 8 tanks or 48,000 pounds of propellant (53,000 pounds total) will put 14,900 pounds of payload (brought to LEO on a separate STS launch) into the 12-hour orbit, and 10,600 pounds to GEO.

- SPACE STATION AND ON-ORBIT REFUELING <u>NOT</u> REQUIRED

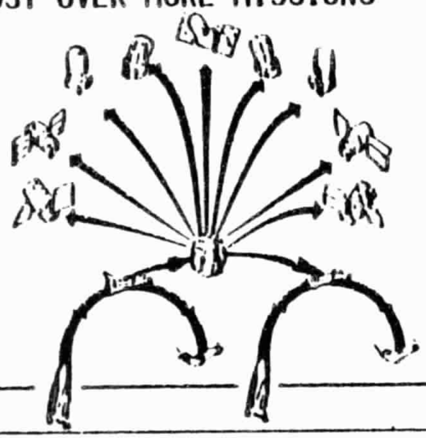
SCENARIO

- LEAVE FREE FLYING TMS ON ORBIT
- RETURN TO GROUND FOR REFUELING
- FUEL CAPACITY: FUEL EFFICIENCY DEPENDENT: (MISSION NEEDS)
  - FREQUENCY OF SWITCHING BASING MODES

POTENTIAL APPROACH

- BASELINE TMS WITH ADD-ON TANK MODULE

✓SPREAD TMS LAUNCH COST
COST OVER MORE MISSIONS

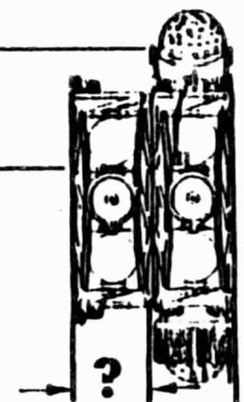


✓PERFORM NEW FUNCTIONS

12000/24000 LB CAPACITY: ONE/TWO OMS KITS

24000 LB: 12/24 HOUR ORBIT SERVICE MISSION

48000 LB: 10600 LB PAYLOAD TO GEO



TMS GROUND BASING TRANSITION TO EARLY SPACE BASING

The initial scenario assumed that on orbit refueling would not be available and that increasing TMS fuel capacity with an add-on tank module would increase staytime on orbit and therefore decrease transport costs. A detailed analysis showed otherwise, with the basic TMS most cost effective, due to its higher fuel efficiency. However, the tank module may be justified for other reasons, as given in the prior chart, including its use for high energy missions. Its potential cost effectiveness in these missions in which the entire stage is expended may lie in the fact that all prior uses of the TMS will help to amortize its acquisition cost, and thus reduce its user price for the expendable mission. This amortization is denied the OTV user, since the flight vehicle cannot economically or functionally perform as a TMS, particularly when ground based, or ground refueled.

TMS BENEFITS ASSESSMENT STUDY
GROUND BASING → EARLY SPACE BASING

- EARLY SPACE BASING DOES NOT REQUIRE A SPACE STATION
- EARLY SPACE BASING DOES NOT REQUIRE ORBITAL REFUELING

<u>SCENARIO</u>:

✓ LEAVE FREE FLYING TMS ON ORBIT FOR STAYTIME DEPENDENT ON PROPELLANT LOAD (DELTA V CAPACITY)

✓ RETURN TO GROUND FOR REFUELING

✓ MAXIMUM FUEL CAPACITY DEPENDS ON:

  - NEED FOR FLEXIBILITY IN SWITCHING BASING MODES
  - EFFECT ON USER FEES
  - INFLUENCE OF SIZE/AGILITY IN MEETING MISSION REQUIREMENTS
  - FUEL UTILIZATION EFFICIENCY (MPG)

- SPACE BASING <u>DOES</u> REQUIRE ENERGY STORAGE/RECHARGE

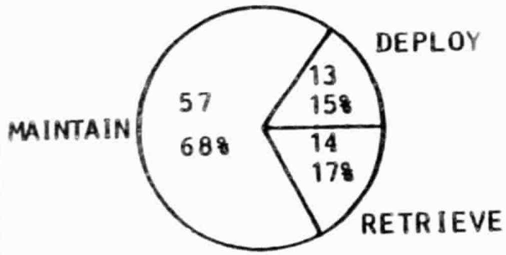
SPACE BASED TMS MISSION MODEL FOR 28.5° ORBIT

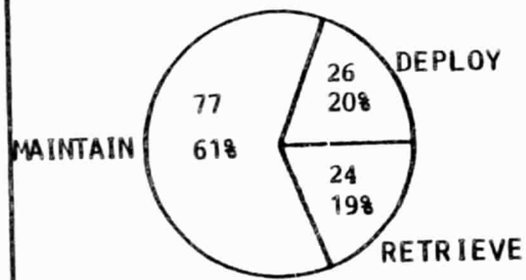
The first step in the space basing analysis was to create low, nominal, and high models, all located at a 28.5° orbit inclination. This location was selected because it provided maximum payload traffic. Contingency missions were not included, reducing the number in the nominal model to 51 missions. These were used in the analysis. Each TMS mission, including shared engagements, was analyzed for bipropellant fuel requirements for each basing scenario, and the number of STS launches identified, whether for ground or on orbit refueling.

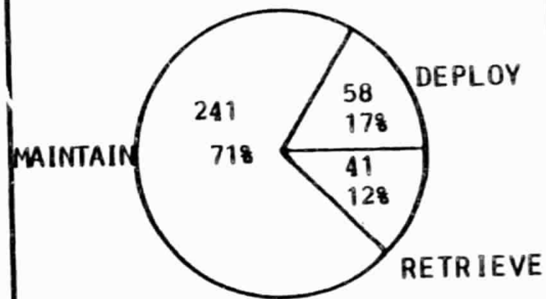
TMS BENEFITS ASSESSMENT STUDY

SPACE BASED TMS MISSION MODEL FOR 28.5^{o} ORBIT

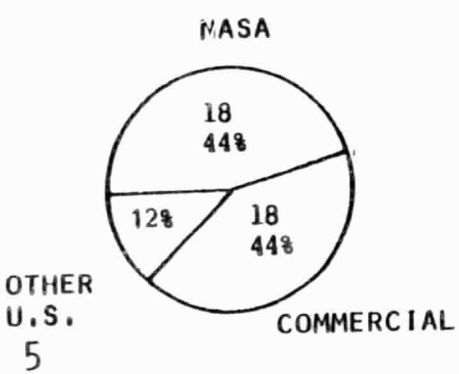
84 ENGAGEMENTS LOW	127 ENGAGEMENTS NOMINAL	346 ENGAGEMENTS HIGH
TMS FLEET SIZE: 2	TMS FLEET SIZE: 2	TMS FLEET SIZE: 3

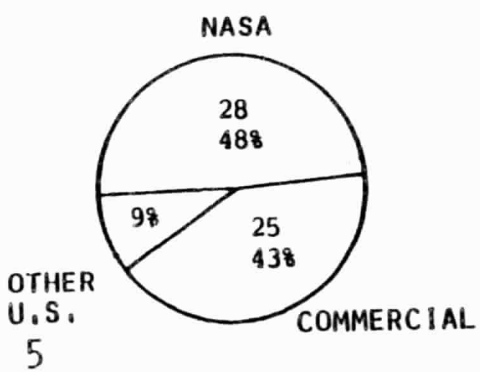


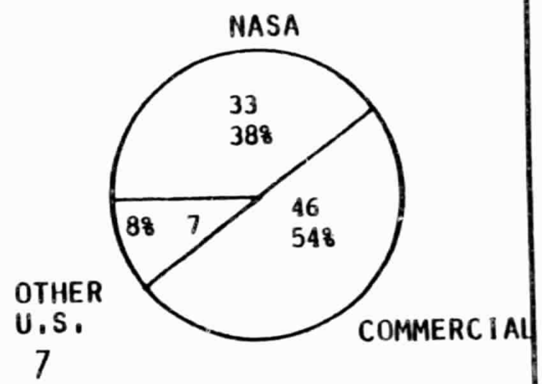




41 MISSIONS 20 SHARED (49%)	58 MISSIONS 34 SHARED (59%)	86 MISSIONS 65 SHARED (76%)







TMS BENEFITS ASSESSMENT STUDY

BASING MODES EVALUATION, 28.5°

SPACE BASING WITH ON ORBIT REFUELING PROVIDES MAXIMUM BENEFITS

Three basic basing modes were compared: Ground basing, space basing with ground refueling, and space basing with on orbit refueling. The first was a reference against which to compare the other modes. The ground refueling analysis started with the largest tank module obtainable in a dedicated launch, which was then reduced in size, with the third case being the Vought add-on module. The fourth case was the TMS alone. Finally, on orbit refueling was added and two approaches were examined: Refueling from the maximum size tank module, and TMS refueling directly from the Orbiter OMS pod tanks. Only delta costs affected by the basing mode were considered. All costs were prorated over the 51 missions. An interesting trend appeared for ground refueling: Fuel load and cost savings were inversely related with the TMS, alone, providing maximum savings even when launches rose from 5 to 29. One reason is that the two smaller configurations benefited from the lower cost of length driven missions, an advantage that would diminish as payloads become Shuttle optimized. Refueling from the tank module was penalized by a high refueling DDT&E assessment of $51M. By far, the most promising refueling method is to use the Orbiter OMS propellant.

TMS REFUELING FROM ORBITER OMS POD TANKS DRAMATICALLY INCREASES BENEFITS

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TMS BENEFITS ASSESSMENT STUDY
BASING MODES EVALUATION, 28.5^{o}

SPACE BASING/REFUELING: MAXIMUM BENEFITS

	REFUEL MODE	W_P TMS/TANK TOTAL	ORBITER CARGO WEIGHT	NO. STS LAUNCHES	LAUNCH COST PER TMS MISS.	TANK DDT&E PER MISS.	INTEG. COST PER MISSION	TOTAL COST PER TMS MISS.
1	GROUND BASED	2157 AVG NA	5927 NA	17 WEIGHT 34 LENGTH	6.65	—	2.5	9.15
2	SPACE BASED, GROUND REFUEL	50014 AVG	60014	5	6.96	1.3	0.25	8.51
3		26969 AVG	33729	7	6.74	0.9	0.34	7.98
4		7574 AVG	13244	7 WEIGHT 11 LENGTH	4.92	0.6	0.88	6.40
5		3945 AVG	7715	10 WEIGHT 19 LENGTH	4.31	—	1.42	5.73 7.154 AVG.
6	TANKER REFUEL	55000	65000	2	2.78	2.3	0.10	5.18
7	OMS POD REFUEL	4314 FOR 2 MISSIONS	4314 FUEL 30[illegible]	9 OF 26 WT. DRIVEN	0.96	0.40 REFUEL COST	0.15* CREW TIME	1.51

*$0.30M PER REFUELING

Space Transportation & Systems Group
Rockwell International

TMS BENEFITS ASSESSMENT STUDY

BASING MODES EVALUATION, 28.5° (contd.)

TMS REFUELING FROM OMS POD TANKS SHOWS MAXIMUM BENEFIT

This expanded version of the prior chart shows the steps used in the analysis. The maximum cargo weights for TMS (2826 lb), cradle (832 lbs) and AFD equipment (112 lb), were used (3770 lb total), plus fuel, for all launches. In all cases, program launch cost is the total of weight and length driven launch costs. For both on orbit refueling cases, it is noted that considerable interest and activity is being shown in developing this technology. An intensive effort is presently underway to develop hardware for a demonstration mission. The plan calls for manual connection of monopropellant lines by EVA in the Orbiter payload bay.

A dramatic benefit is shown for on-orbit refueling of a space based TMS from the Orbiter integral OMS. For each of the 26 Orbiter launches, the average OMS offload of 4314 pounds was sufficient for two TMS missions. Charge for the on-orbit refueling is estimated at \$0.30M. DDT&E for OMS modifications is set at \$20M.

TMS BENEFITS ASSESSMENT STUDY
BASING MODES EVALUATION, 28.5°
LENGTH AND WEIGHT DRIVEN LAUNCHES

	REFUEL MODE	W_P TMS/TANK TOTAL	ORBITER CARGO WEIGHT	NO. STS LAUNCHES	COST PER LAUNCH $M	PROGRAM LAUNCH COST	LAUNCH COST PER TMS MISS. (PRORATED OVER 51 MISSIONS)	TANK DDT&E PER MISS. (PRORATED OVER 51 MISSIONS)	INTEG. COST PER MISSION (PRORATED OVER 51 MISSIONS)	TOTAL COST PER TMS MISS. (PRORATED OVER 51 MISSIONS)
1	GROUND BASED	2157 AVG NA	5927 NA	17 WEIGHT 34 LENGTH	8.63 5.654	338.9	6.646	—	2.5	9.146
2	SPACE BASED, GROUND REFUEL	50014 AVG	60014	5	71	355	6.96	1.3	0.25	8.51
3		26969 AVG	33729	7	49.12	343.9	6.74	0.9	0.34	7.98
4		7574 AVG	13244	7 WEIGHT 11 LENGTH	19.289 10.519	250.7	4.916	0.6	0.88	6.396
5		3945 AVG	7715	10 WEIGHT 19 LENGTH	11.236 5.654	219.8	4.31	—	1.42	5.73 7.154 AVG.
6	TANKER REFUEL	55000	65000	2	71	142	2.78	2.3	0.10	5.18
7	OMS POD REFUEL	4314 FOR 2 MISSIONS	4314 FUEL 300 ASE	9 OF 26 WT. DRIVEN	5.03 FUEL 20% DISC. 0.44 ASE	49.23	0.96	0.40 OMS DDT&E	0.15* CREW TIME	1.51

*$0.30M PER REFUELING

Space Transportation & Systems Group
Rockwell International

TMS BENEFITS ASSESSMENT STUDY
BASING MODE EVALUATION, 28.5°, ALL LAUNCHES WEIGHT DRIVEN

If all launches were weight driven, line items 3 and 4 change places, in order of descending cost per mission. Line items 3 and 5 become virtually equal in cost. In fact, the $2.78\bar{M}$ spread shown for the four space based, ground refueled cases, reduces to $0.701\bar{M}$ when all launches are weight driven. Nevertheless, the average cost saving per mission for this basing mode over ground basing improves from about $2\bar{M}$ to $3\bar{M}$. For OMS pod refueling, there is virtually no change, relative to ground basing, with the delta cost saving rising from $7.64\bar{M}$ to $7.79\bar{M}$. OMS refueling savings, relative to the space based, ground refuel mode (average cost per mission: $7.154\bar{M}$, including length driven launches; $8.15\bar{M}$, all launches weight driven), show a modest drop from $5.64\bar{M}$ to $4.8\bar{M}$.

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TMS BENEFITS ASSESSMENT STUDY
BASING MODES EVALUUTION, 28.5°
ALL LAUNCHES WEIGHT DRIVEN

	REFUEL MODE	W_P TMS/TANK TOTAL	ORBITER CARGO WEIGHT	NO. STS LAUNCHES	COST PER LAUNCH $\bar{\$M}$	PROGRAM LAUNCH COST	LAUNCH COST PER TMS MISS.	TANK DDT&E PER MISS.	INTEG. COST PER MISSION	TOTAL COST PER TMS MISS.
							PRORATED OVER 51 MISSIONS			
1	GROUND BASED	2157 AVG	5927	51	8.63	440.13	8.63	-	2.5	11.13
2	SPACE BASED, GROUND REFUEL	50014 AVG	60014	5	71	355	6.96	1.3	0.25	8.51
3		26969 AVG	33729	7	49.12	343.9	6.74	0.9	0.34	7.98
4		7574 AVG	13244	18	19.289	347.2	6.81	0.6	0.88	8.288
5		3945 AVG	7715	29	11.236	325.84	6.39	-	1.42	7.809
										8.15 AVG
6	TANKER REFUEL	55000	65000	2	71	142.0	2.78	2.3	0.10	5.18
7	OMS POD REFUEL	4314 FOR 2 MISSIONS	4314 FUEL 300 ASE	26	5.03 FUEL 20% DISO. 0.44 ASE	142.22	2.79	0.40 OMS DDT&E	0.15* CREW TIME	3.34

TMS BENEFITS ASSESSMENT STUDY

CONTENTS

TECHNICAL DISCUSSION - TASK 4.1

MISSION MODELS AND PAYLOAD REQUIREMENTS

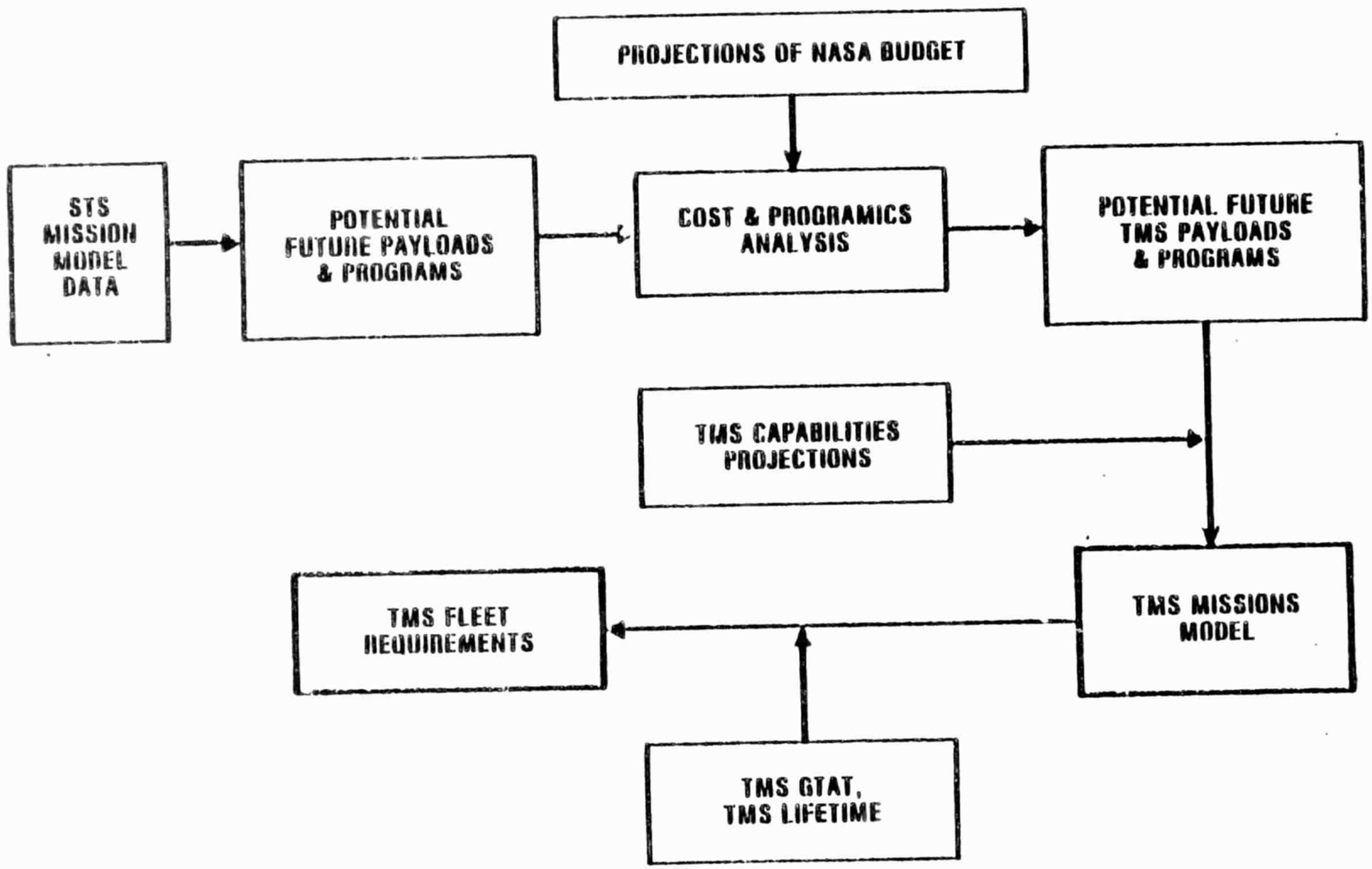
TMS MISSION MODEL LOGIC AND CAPTURE

For the past 3 years, Rockwell has had a program underway to identify programs and payloads that could fly on the STS in the next two decades. Using this data on planned and potential programs, a list of potential future TMS payloads was generated. To keep this projection within realistic constraints of affordability, a cost analysis was performed on each program to determine a ROM cost and reduce the number of individual TMS programs to fit within realistic projections of the NASA budget. This step ultimately determined the composition of the TMS mission models by constraining TMS payloads to fit within NASA budget projections.

Once the TMS payloads had been determined, the applicability of the baseline TMS to service, deploy or retrieve these payloads was determined. Only one payload (DOD) was beyond TMS capabilities and was not included in the models. As much as was possible, the TMS mission models shared TMS capabilities (deploy, retrieve, or service) between payloads in order to reduce the number of TMS flights and keep transportation costs as low as possible.

After the TMS mission models had been prepared, the results of Task 4.2 regarding achievable TMS ground turn-around time (GTAT) was used to determine how many TMS vehicles would be required to fly these missions.

TMS MISSION MODEL LOGIC AND CAPTURE



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TMS MISSION MODEL ASSUMPTIONS

As part of Task 4.1, several TMS mission models reflecting different levels of TMS utilization were produced. The primary driving feature of the various models were for the low TMS mission model, a low acceptance of TMS services under a constant NASA budget; a constant NASA budget and acceptance of the TMS for payloads above 160 nautical miles in the nominal TMS model; and for the high TMS mission model, a slightly increased NASA budget with the same acceptance of TMS services to payloads.

Some DOD missions at low altitudes were assumed captured by the TMS in the nominal and high mission models, but for a "low acceptance" TMS model, no DOD payloads were captured in the low mission model.

Based upon current information, a single commercial MPS effort was included in each of the TMS mission models. Such a program, involving several free flying MPS factories in LEO requires periodic servicing for commercial viability. In the nominal and low TMS mission model, a low level of commercial TMS work was assumed with a higher level of commercial MPS activity in the high model. For the low TMS model, a TMS servicing mission was assumed only if an orbiter was not required in the vicinity to deliver or retrieve a MPS factory, but in the nominal model, TMS servicing, retrieval and deployment of the MPS system was assumed to eliminate the orbiter constraints on a multiple factory MPS system. A higher level of MPS activity was postulated in the high TMS model with TMS services.

GEO missions were tied to the servicing of large GEO communications platforms with their resultant concentration of capital and hardware. While other reasons for TMS GEO servicing exist, no better single justification for GEO TMS missions exists, with the realization that the TMS once at GEO can service other GEO satellites than platforms. In the low TMS mission model, only a GEO servicing demonstration is shown. For the nominal TMS mission model, GEO servicing missions are included to an Atlantic and a Pacific platform cluster, while in the high TMS mission model, missions to service an Indian Ocean platform cluster are added.

In all TMS mission models, if a payload has been deployed by the TMS in LEO, it is expected that TMS will retrieve the payload at the end of its expected lifetime for return to the ground or controlled reentry.

TMS MISSION MODEL
ASSUMPTIONS

<u>NOMINAL MODEL</u>

- CONSTANT FUNDING LEVEL IN NASA
  - TMS PLACEMENT, RETRIEVAL, SERVICING TO FREE FLYERS ABOVE 160 NAUTICAL MILES
- CAPTURE OF SOME LOW-ALTITUDE DoD MISSIONS
- NOMINAL LEVEL FREE-FLYING COMMERCIAL MATERIALS PROCESSING SATELLITES (MPS)
- RETRIEVAL OF LEO PAYLOADS AT END OF MISSION
- EIGHT (8) GEO SERVICING MISSIONS

<u>LOW MODEL</u>

- TMS SERVICES TO LARGE OBSERVATORIES
- TMS SERVICES TO PAYLOADS ABOVE BASELINE STS CAPABILITIES
- COMMERCIAL MPS MISSIONS ONLY IF ORBITER NOT REQUIRED
- NO DoD MISSIONS
- RETRIEVAL OF TMS PAYLOADS AT END OF MISSION
- 1 GEO SERVICING DEMONSTRATION MISSION

<u>HIGH MODEL</u>

- INCREASED NASA BUDGET
- NO NEW DoD MISSIONS OVER NOMINAL
- HIGHER LEVEL FREE FLYING COMMERCIAL MPS
- RETRIEVAL OF LEO PAYLOADS AT END OF MISSION
- TEN (10) GEO SERVICING MISSIONS

TMS BENEFITS ASSESSMENT STUDY

TASK 4.1 - MISSION MODELS, GROUND BASED

This chart summarizes the results of the TMS mission models, and Task 4.1. An engagement is defined as either deployment of a payload, retrieval, or maintenance (scheduled service) performed on a pyaload. The chart summarizes the results for the 3 models shown.

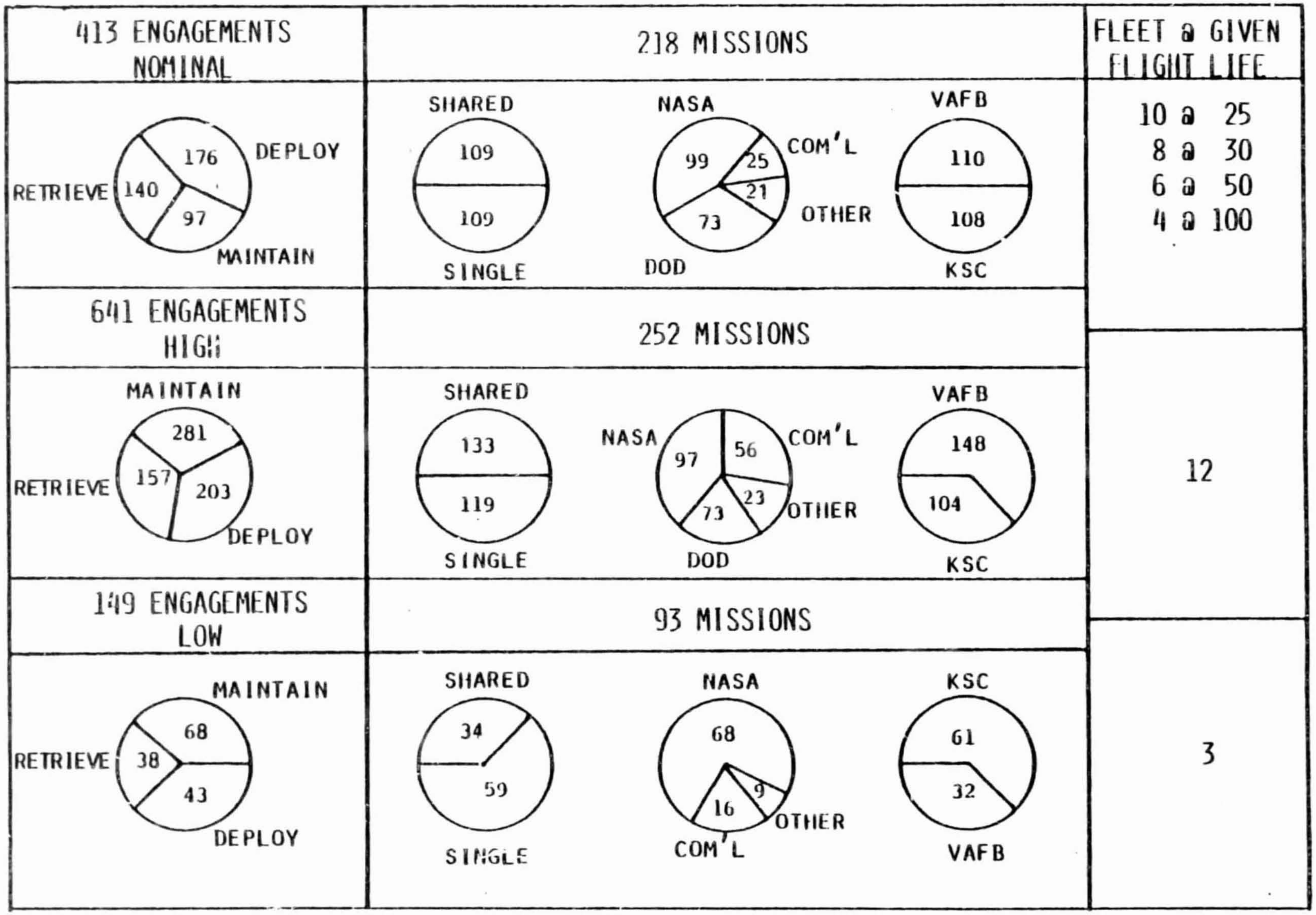
Several engagements may be shared on a single TMS mission, a single TMS flight might have the TMS deploying one payload, servicing a second, and retrieving a third. The results of this analysis is shown, as well as the split between VAFB and KSC launches of the TMS, and a breakdown of the TMS missions by user.

Using the results of Task 4.2, indicating a minimum of 40 days GTAT for the TMS, an analysis has been made of the number of TMS vehicles necessary to accommodate these missions. This is also shown. Fleet size was driven by the assumed flight life of 25.

For a 30-flight life, fleet size drops to 8; 50 fights, 6 vehicles; and 100 flights, 4 vehicles.

TMS BENEFITS ASSESSMENT STUDY

TASK 4.1 - MISSION MODELS, GROUND BASED



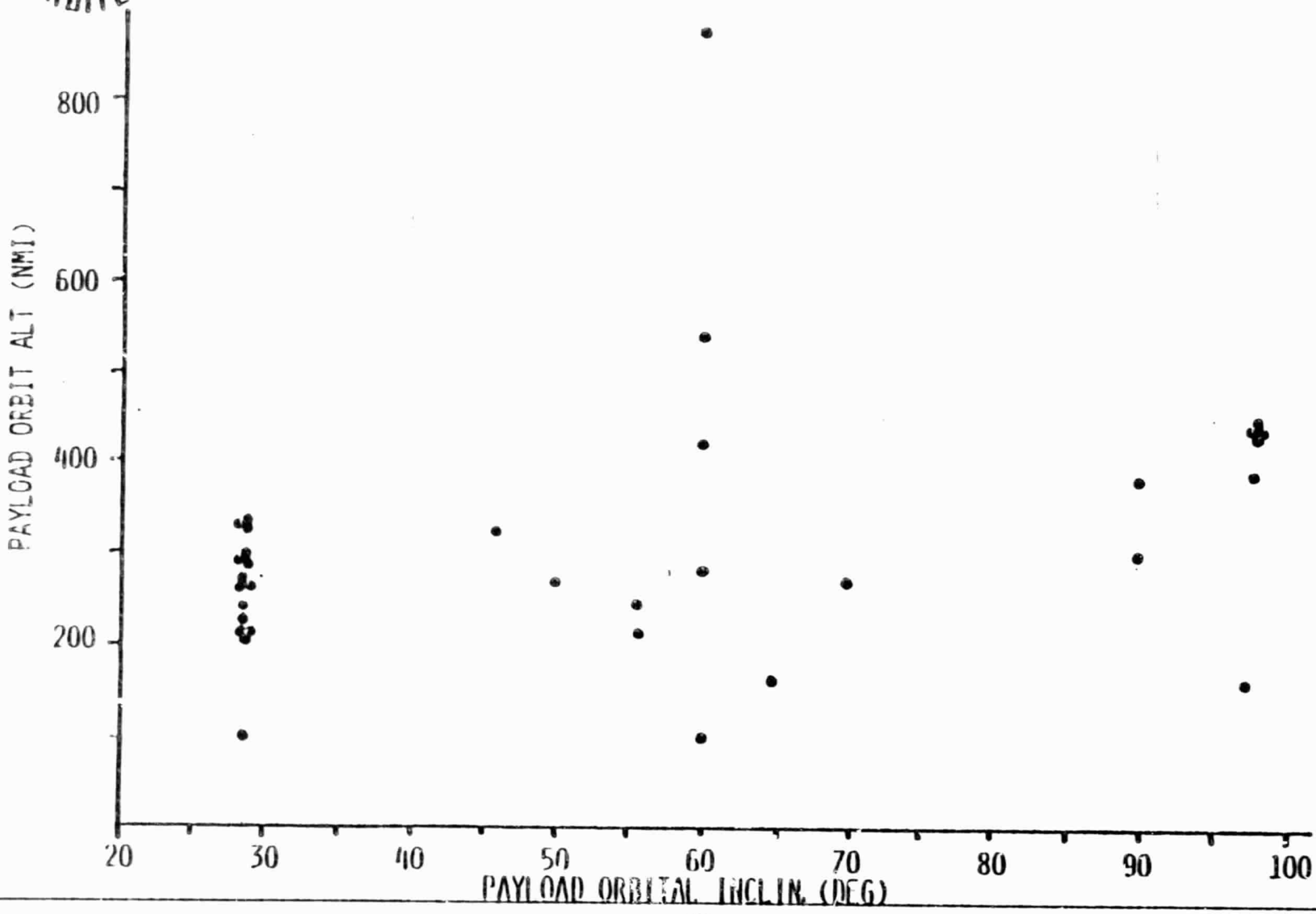
TMS PAYLOADS

BY ORBIT ALTITUDE, INCLINATION

From all TMS models, the payloads postulated to require TMS deployment, retrieval or servicing are plotted as payload inclination versus altitude. It may easily be seen that the payloads cluster in two regions. The cluster of payloads at 28.5° corresponds to payloads launched into LEO after launch, due east from KSC, while the other cluster at about 98° and 400 nautical miles corresponds to payloads in sun-synchronous orbit. Payloads with multiple deployments, retrievals, or servicing missions are only plotted once.

If space-basing a TMS is considered, these two orbital locations are the prime candidates for the space-based TMS. However, other factors, particularly the nodal crossing problem, make space basing a TMS in sun-synchronous orbit much more difficult than a 28.5° orbit.

TMS PAYLOADS
BY ORBIT ALTITUDE, INCLINATION



TMS PAYLOADS

The next two charts summarize most characteristics of the payloads in the TMS mission models. Included in the tables are the name of the payload, its expected first launch date, the TMS model it is included in (Low, or Nominal, or High TMS Mission Model), the TMS capabilities it utilizes (Deploy, Service or Retrieve), the beginning of life weight on orbit, the payload orbit and inclination. If there is a difference between the models in TMS capabilities used, this is also indicated in the tables.

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SPACE SHUTTLE ORBITER

TMS PAYLOADS

NAME	DATE	MODEL	TMS SERVICE	WEIGHT POUNDS	INCL DEG	ALT NMI	NAME	DATE	MODEL	TMS SERVICE	WEIGHT POUNDS	INCL DEG	ALT NMI
SPACE TEL	1985	M,H	D,S,R	24400	28.5	324	TOPEX	1989	M,H	D,S,R	2970	65	162
SCE	1990	M	S,R	2200	28.5	324	ADV.ETH.OBS II	1999	L,M,H	D	?	60	880
	1990	H	D,S,R	2200	28.5	324	OPT'L ETH. OBS	2000	L,M,H	D	?	60	540
HLSE	1998	M,H	D	1760	28.5	324	ERBS	1985	L,M	D,	4400	46	324
IR INTERF	1996	L,M,H	D,S	49500	28.5	2.97		1985	H	D,S,R	4400	46	324
EUVE	1986	M,H	R	880	28.5	297	SNOW & SOIL	1993	L,M	D,R	1995	56°	251
HPS	1987	L	S,R	000	28.5	297	MOISTURE	1993	H	D,S,R	1995	56°	251
	1988	M,H	D,S,R	24000	28.5	297	LARS 3	1996	L,M	D,R	2575	60°	421
LDEF	1984	L,M,H	D,R	9900	28.5	275		1996	H	D,S,R	2575	60	421
AXAF	1990	L,M,H	D,S,R	26400	28.5	270	LARS 4	1997	M	D,R	4190	60	151
EUVSE	1999	M,H	D	3520	28.5	270		1997	H	D,S,R	4190	60	151
CTE	1993	M	D,R	6600	28.5	243	LARS 6	2000	L,M,H	D	6890	60	281
	1993	H	D,S,R	6600	28.5	243	GRAV.PROBE B	1994	L,M,H	D	3370	90°	270-325
VLST	1996	L,M,H	D	50000	28.5	229	COBE	1987	L,M,H	R	3125	SUN	SYNC
GRO	1988	L,M,H	D,S,R	24200	28.5	216	LANDSAT	1982	L,M	D,R	3500	SUN	SYNC
XTE	1989	M	D,R	2200	28.5	216		1982	H	D,S,R	3500	SUN	SYNC
	1989	H	D,S,R	2200	28.5	216	FIREX-A, B	1989	L,H,H	D,R	?	90°?	378
SXE	1992	H	D,R	2860	28.5	216	MAG FIELD SURVEYOR	1990	M,H	D,R	1760	97°	162
	1992	H	D,S,R	2860	28.5	216							
UARS	1988	L,M,H	D,R	3140	50/70	270	ADV.THERMAL	1991	L,M,H	D,R	1760	98°	378
CRO	1993	L,M,H	D,S,R	39600	56	216	MAPPER						

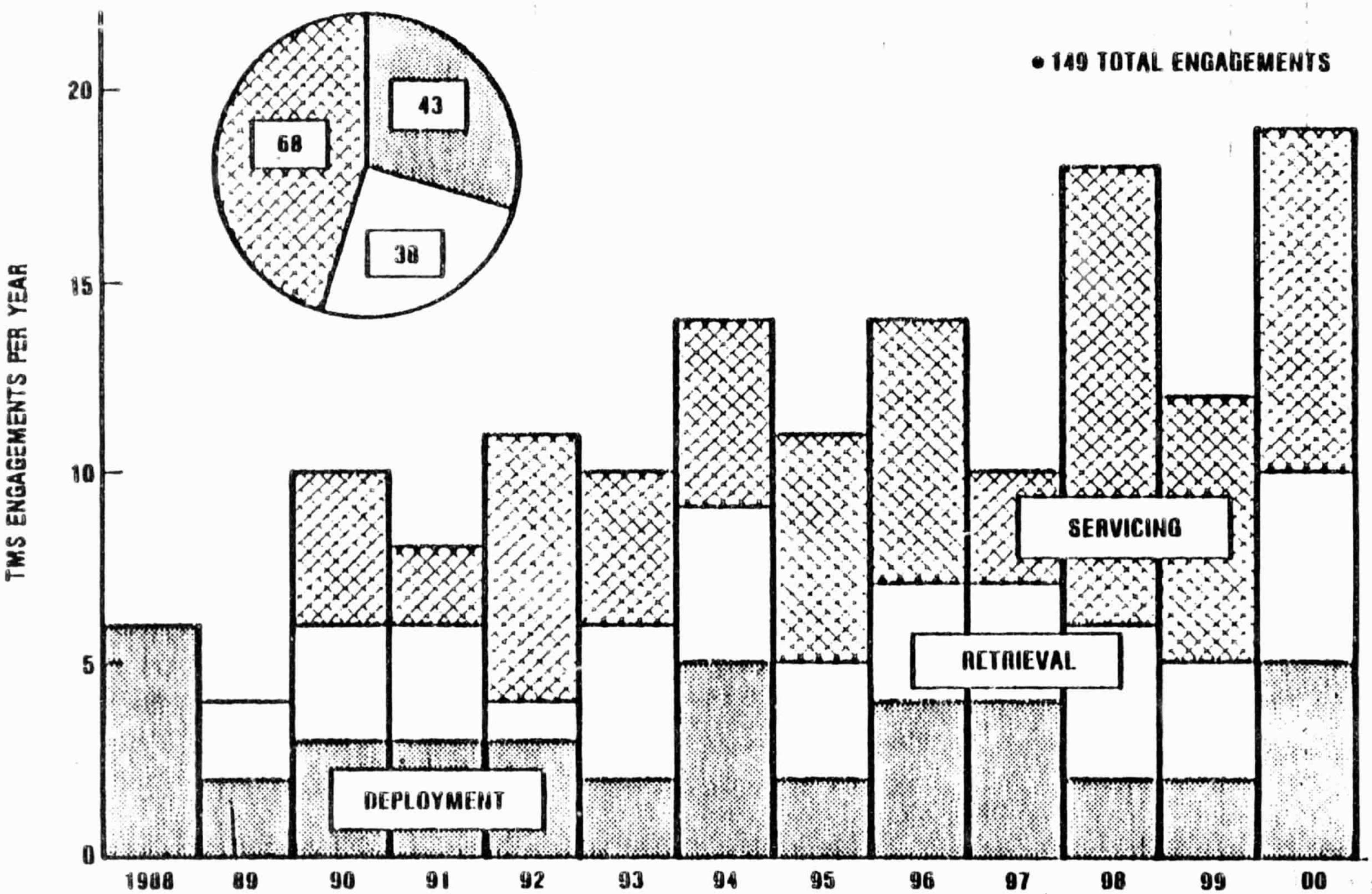
THS PAYLOADS – (CONTINUED)

NAME	DATE	MODEL	THS SERVICE	WT LBS	INCL DEG	ALT NMI								
NOAA	1982	L,M,H	D,R	5-10,000	SUN	SYNC								
DoD		M,H	D,R											
GEO DEMO	1997	L	S	5000	0	GEO								
SERVICE	1991	M,H	S		0	GEO								
GEO PLAT SERVICE	1995	M,H	S	5000										
SUBSAT	1988	M,H	D,R	VARIOUS		STS								

LOW TMS MODEL, TMS ENGAGEMENTS

A TMS engagement is defined as a TMS deployment of a payload, servicing performed on a payload, or TMS retrieval of a payload. The facing chart shows the low TMS mission model breakdown of 149 total TMS engagements, broken down on an annual basis. As per the baseline TMS, it was assumed that the TMS would be available in 1988 for deployments, 1989 for retrievals, and 1990 for servicing.

LOW TMS MODEL TMS ENGAGEMENTS



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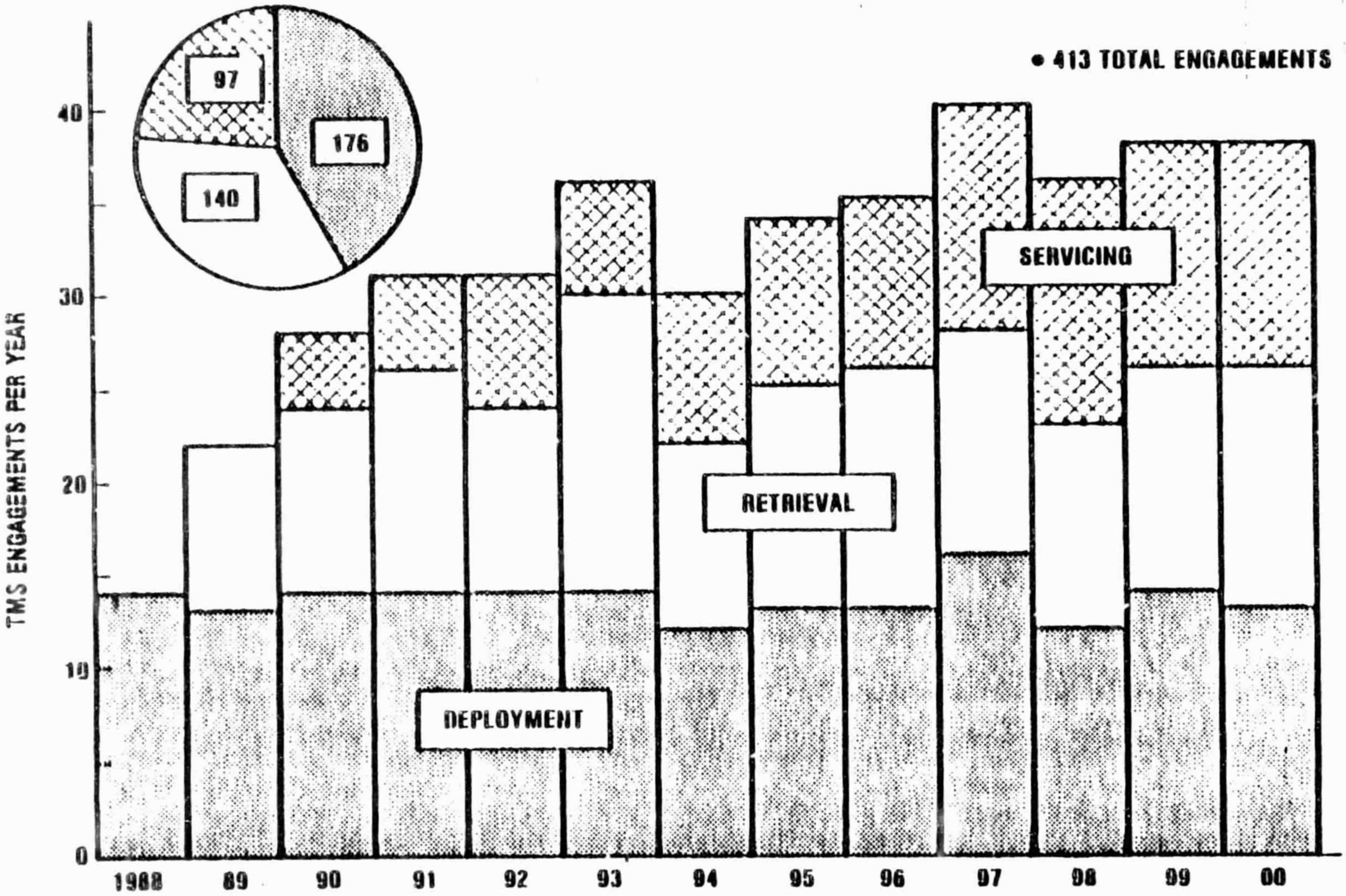
NOMINAL TMS MODEL/TMS ENGAGEMENTS

A TMS engagement is defined as a TMS deployment of a payload, servicing performed on a payload or TMS retrieval of a payload. The facing chart shows the low TMS mission model breakdown of 413 total TMS engagements, broken down on an annual basis. As per the baseline TMS, it was assumed that the TMS would be available in 1988 for deployments, 1989 for retrievals, and 1990 for servicing.

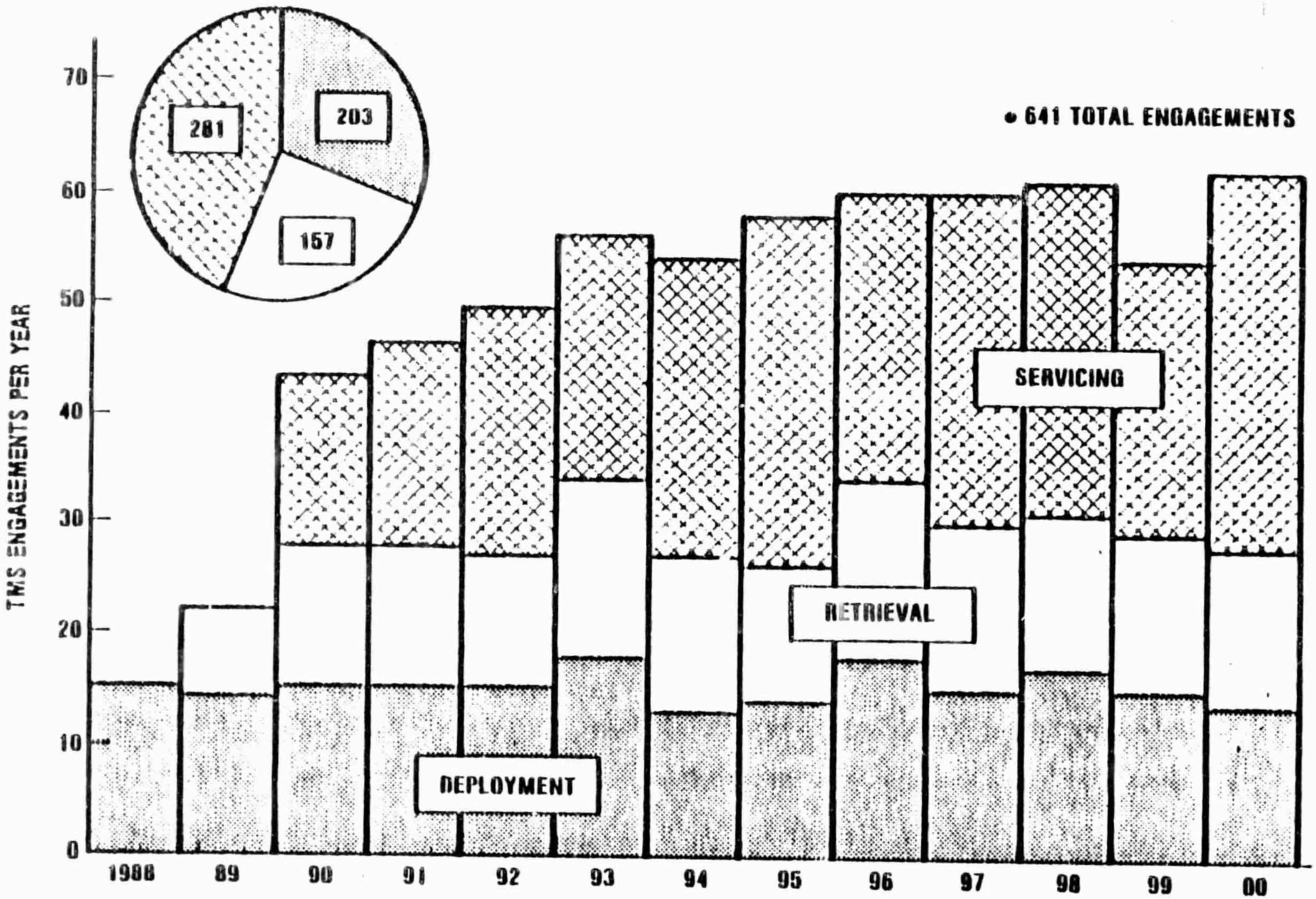
NOMINAL TMS MODEL TMS ENGAGEMENTS



HIGH TMS MODEL, TMS ENGAGEMENTS

A TMS engagement is defined as a TMS deployment of a payload, servicing performed on a payload or TMS retrieval of a payload. The facing chart shows the low TMS mission model breakdown of 641 total TMS engagements, broken down on an annual basis. As per the baseline TMS, it was assumed that the TMS would be available in 1988 for deployment, 1989 for retrievals, and 1990 for servicing.

HIGH TMS MODEL TMS ENGAGEMENTS



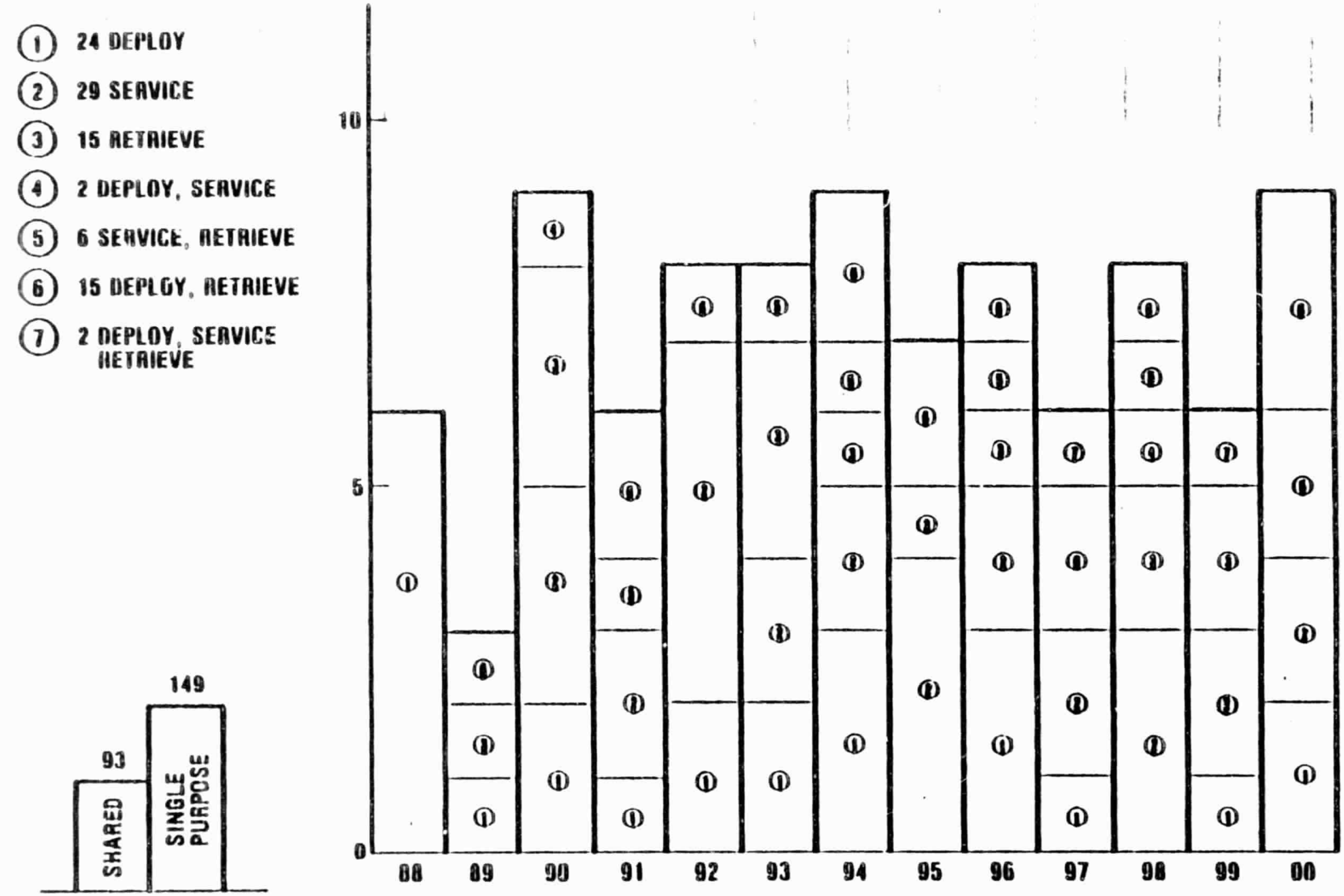
LOW MODEL REDUCTION OF TMS FLIGHTS THROUGH SHARED/MULTIPURPOSE MISSIONS

Several TMS engagements may be performed on a single TMS mission. As an example, a single TMS mission may see a TMS deploy a payload, transition to another orbit to service a second payload, and then transition to a third orbit and retrieve a third payload. The chart shown indicates the reduction of TMS flights required through the use of shared or multipurpose missions. As indicated on the facing chart, using multipurpose TMS missions drops the number of missions from 149 required if only a single engagement is performed per mission, to 93 when multipurpose missions are considered.

The specific type of mission performed per year is given, with an annual breakdown of the total number of TMS missions by year in the low TMS mission model.

At this point in the study, multiple manifesting of deployed payloads was not included. It was later added as a delta benefit to the analysis for the nominal model, only.

LOW MODEL REDUCTION OF TMS FLIGHTS THROUGH SHARED/MULTIPURPOSE MISSIONS



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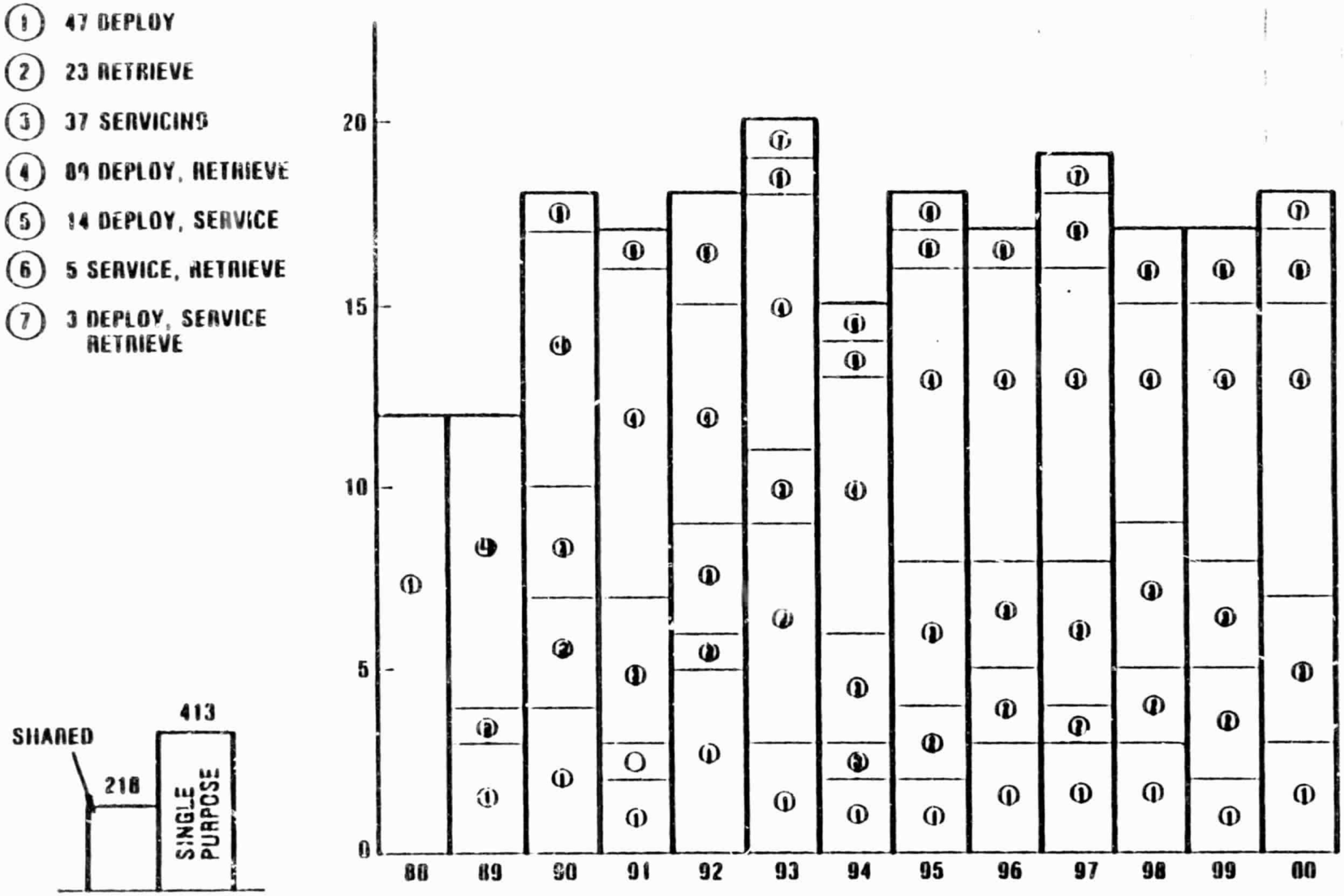
NOMINAL MODEL REDUCTION OF TMS FLIGHTS THROUGH SHARED/MULTIPURPOSE MISSIONS

Several TMS engagements may be performed on a single TMS mission. As an example, a single TMS mission may see a TMS deploy a payload, transition to another orbit to service a second payload, and then transition to a third orbit and retrieve a third payload. The chart shown indicates the reduction of TMS flights required through the use of shared or multi-purpose missions. As indicated on the facing chart, using multipurpose TMS missions drops the number of missions from 413 required if only a single engagement is performed per mission, to 218 when multipurpose missions are considered.

The specific type of mission performed per year is given, with an annual breakdown of the total number of TMS missions by year in the nominal TMS mission model.

At this point in the study, multiple manifesting of deployed payloads was not included. It, plus increased sharing of deploy/retrieve missions, was later added as a delta benefit to the analysis, for this nominal model, only. The result was an $800M reduction in TMS program cost.

NOMINAL MODEL REDUCTION OF TMS FLIGHTS THROUGH SHARED/MULTIPURPOSE MISSIONS



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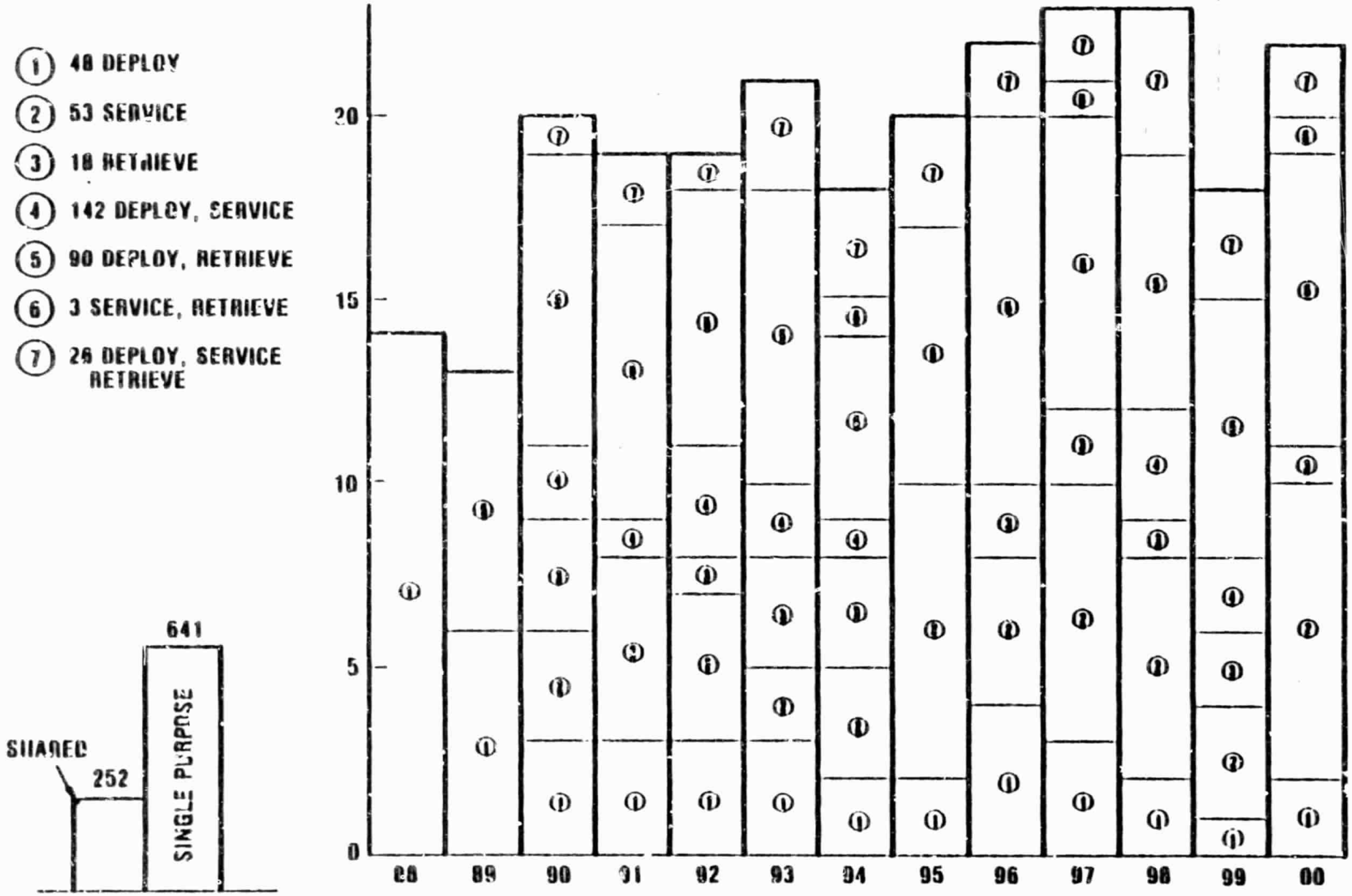
HIGH MODEL REDUCTION OF TMS FLIGHTS THROUGH SHARED/MULTIPURPOSE MISSIONS

Several TMS engagements may be performed on a single TMS mission. As an example, a single TMS mission may see a TMS deploy a payload, transition to another orbit to service a second payload, and then transition to a third orbit and retrieve a third payload. The chart shown indicates the reduction of TMS flights required through the use of shared or multipurpose missions. As indicated on the facing chart, using multipurpose TMS missions drops the number of missions from 641 required if only a single engagement is performed per mission, to 252 when multipurpose missions are considered.

The specific type of mission performed per year is given, with an annual breakdown of the total number of TMS missions by year in the high TMS mission model.

At this point in the study, multiple manifesting of deployed payloads was not included. It was later added as a delta benefit to the analysis, for the nominal model, only.

HIGH MODEL REDUCTION OF TMS FLIGHTS THROUGH SHARED/MULTIPURPOSE MISSIONS



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TMS REFERENCE MISSIONS

In order to help provide detailed mission data for the TMS costing, performance, operations, and missions analysis, 5 "strawman" missions were developed as representative of almost all TMS missions, and the TMS missions divided among them. From within these mission classes, a single mission was chosen for a more detailed analysis to drive out any major considerations overlooked in a more cursory analysis.

The specific missions chosen from within each category are as follows:

Mission 1: LEO satellites: TMS deployment of GTE (Gamma-Ray Timing Explorer) to 243 nmi, TMS service of AXAF, 270 nmi), and TMS retrieval of GRO (216 nmi) to 160 nmi for shuttle return, on a single multifunction mission.

Mission 2: GEO servicing: TMS transfer to GEO, using an add-on tank module, or an advanced OTV, for TMS servicing of a GEO platform. The potential for a TMS orbital walk along GEO to service other GEO satellites (4^{o} max spacing) until TMS fuel was exhausted, was also examined.

Mission 3: Polar satellites: TMS transfer of Landsat spacecraft from space shuttle into sun synchronous orbit, then TMS transfer to and retrieval of second, co-orbiting Landsat for return to earth for refurbishment.

Mission 4: Contingency servicing: The main objective of this mission was to demonstrate the minimum TMS GTAT, so it was postulated that, upon failure of a high value, orbiting satellite, the TMS would be included on the next available STS mission with minimum TMS turn-around time. On-orbit, the TMS would transfer to the disabled satellite, service it, then return to LEO for STS return to the ground.

Mission 5: Subsatellite: To accomplish this mission, and drive out orbiter/TMS proximity operations requirements, it was postulated that the TMS would deploy a payload 100 nmi ahead of the orbiter path, then return to the payload bay and berth. After 24 hours, the TMS would be relaunched to orbit/inspect the orbiter, then reberth. After some period of time, the TMS would rendezvous with the co-orbiting payload, redeploy it into position 100 nmi behind the orbiter path, then reberth with the orbiter. Finally, the TMS would relaunch, and fetch the co-orbiting payload back to the orbiter, reberth, and return to the ground.

No major "showstoppers" were found in this analysis, and the results were used in various other parts of this study.

C-2

TMS REFERENCE MISSIONS

- 5 "STRAWMAN" MISSIONS DEVELOPED FOR COSTING, PERFORMANCE, OPERATIONS, AND MISSIONS ANALYSIS
- USED AS GENERAL "CLASSES" OF TMS MISSIONS

<u>TMS MISSION CLASS</u>

1 - LEO SATELLITES (DEPLOY, RETRIEVE, SERVICE ETR ONLY)

2 - GEO SATELLITES (SERVICE ONLY)

3 - POLAR SATELLITES (DEPLOY, RETRIEVE, SERVICE)

4 - CONTINGENCY SERVICE MISSIONS (SERVICE ONLY, WTR AND ETR)

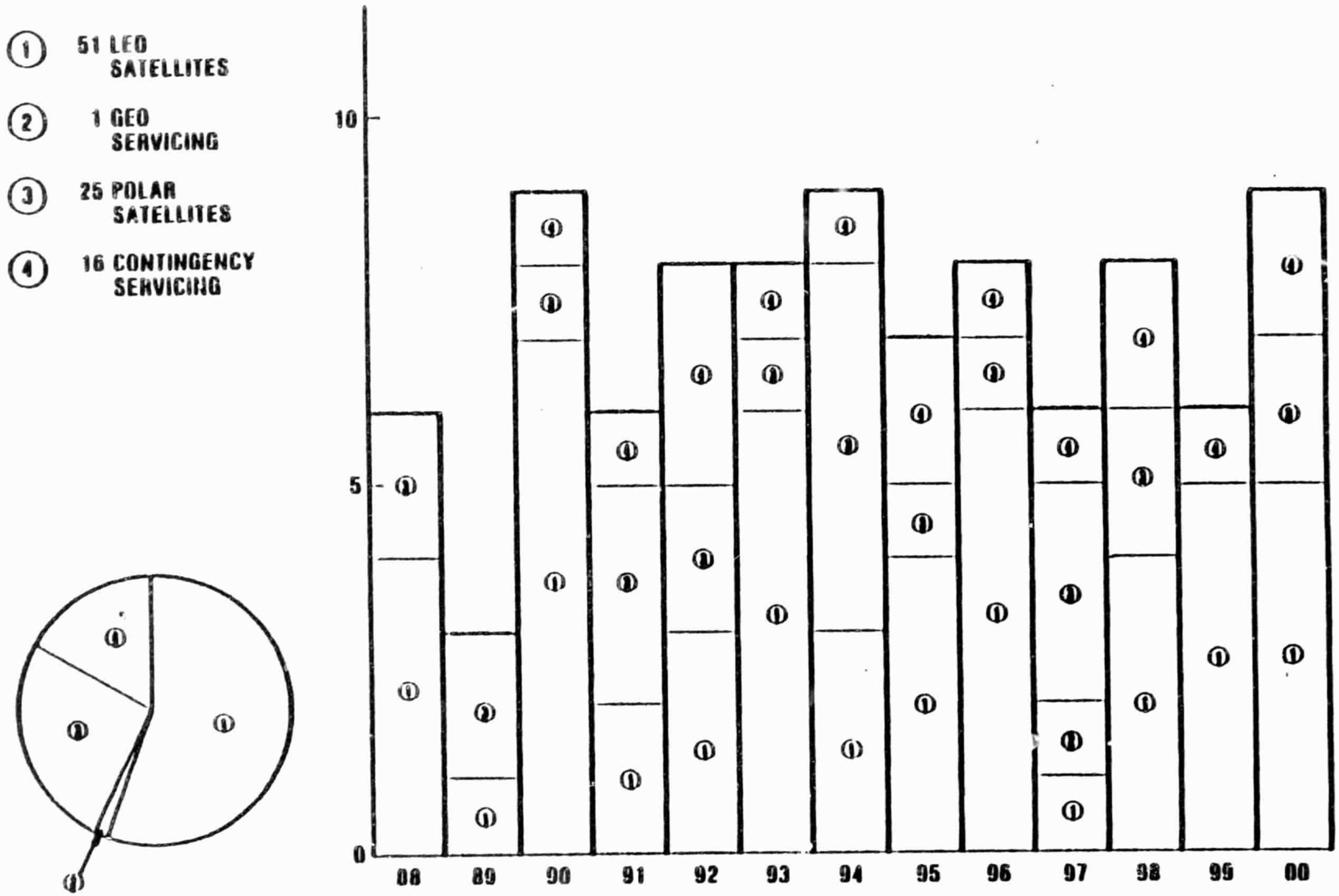
5 - SUBSATELLITE MISSIONS

LOW TMS MISSION MODEL

The low TMS mission model, as described previously, may be divided into the five reference missions. The facing chart shows how the low TMS mission model breaks down by year with these missions. A pie chart in the lower left-hand corner shows the relative proportion of each type of mission.

In the low TMS model, no subsatellite TMS missions were included. Most missions in this model are to deploy, service, or retrieve satellites from KSC.

LOW TMS MISSION MODEL
(93 TOTAL MISSIONS)



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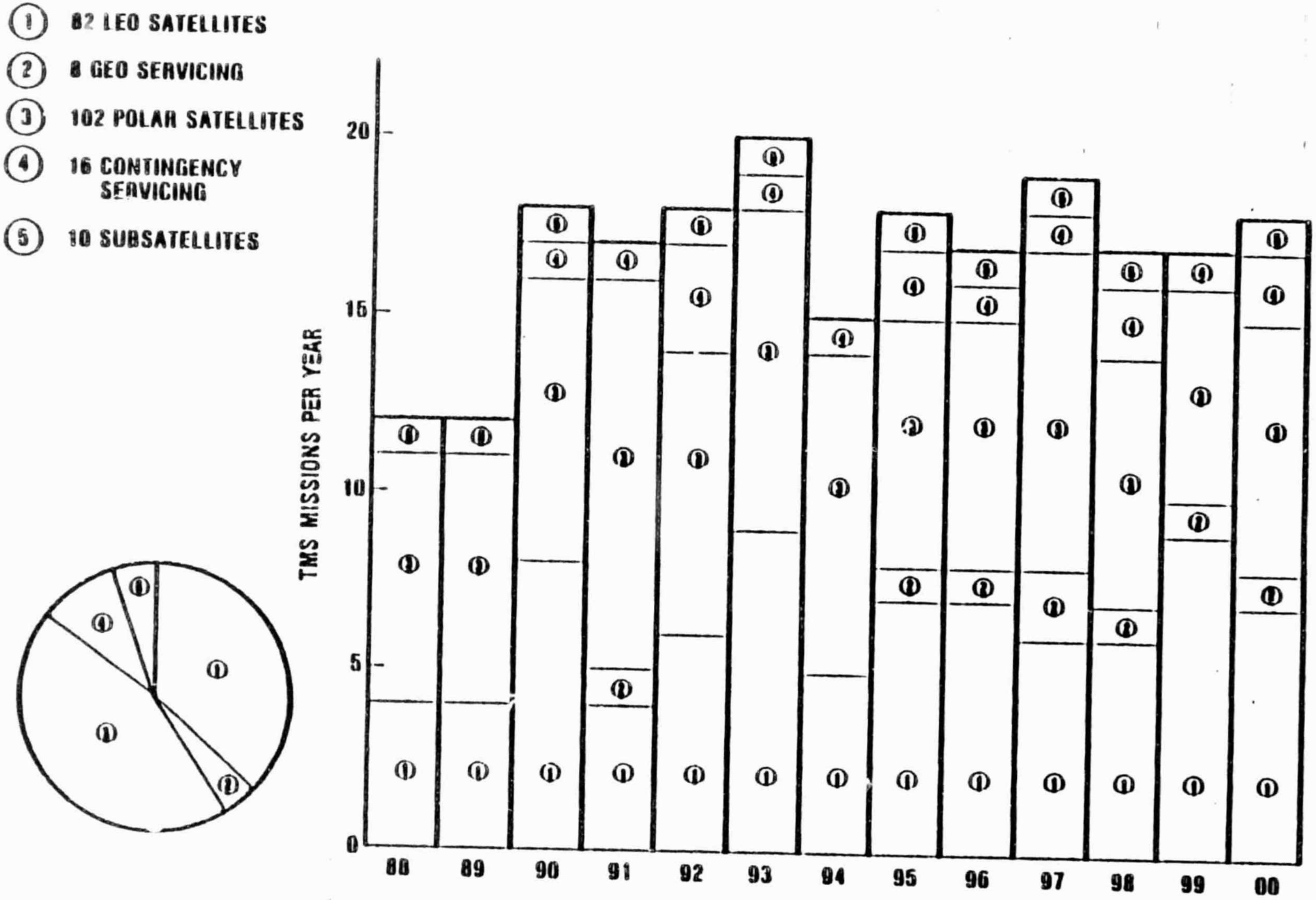
NOMINAL TMS MISSION MODEL

The nominal TMS mission model, as described previously, may be divided into the five reference missions. The facing chart shows how the nominal TMS mission model breaks down by year with these missions. A pie-chart in the lower left-hand corner shows the relative proportion of each type of mission.

In this model, the large percentage of TMS missions flying into polar orbit, compared to the low model, is primarily due to the difficulties encountered in manifesting multiple engagements on a single TMS flight, due to the nodal-crossing problem and its resultant plane change problem.

NOMINAL TMS MISSION MODEL (218 TOTAL MISSIONS)

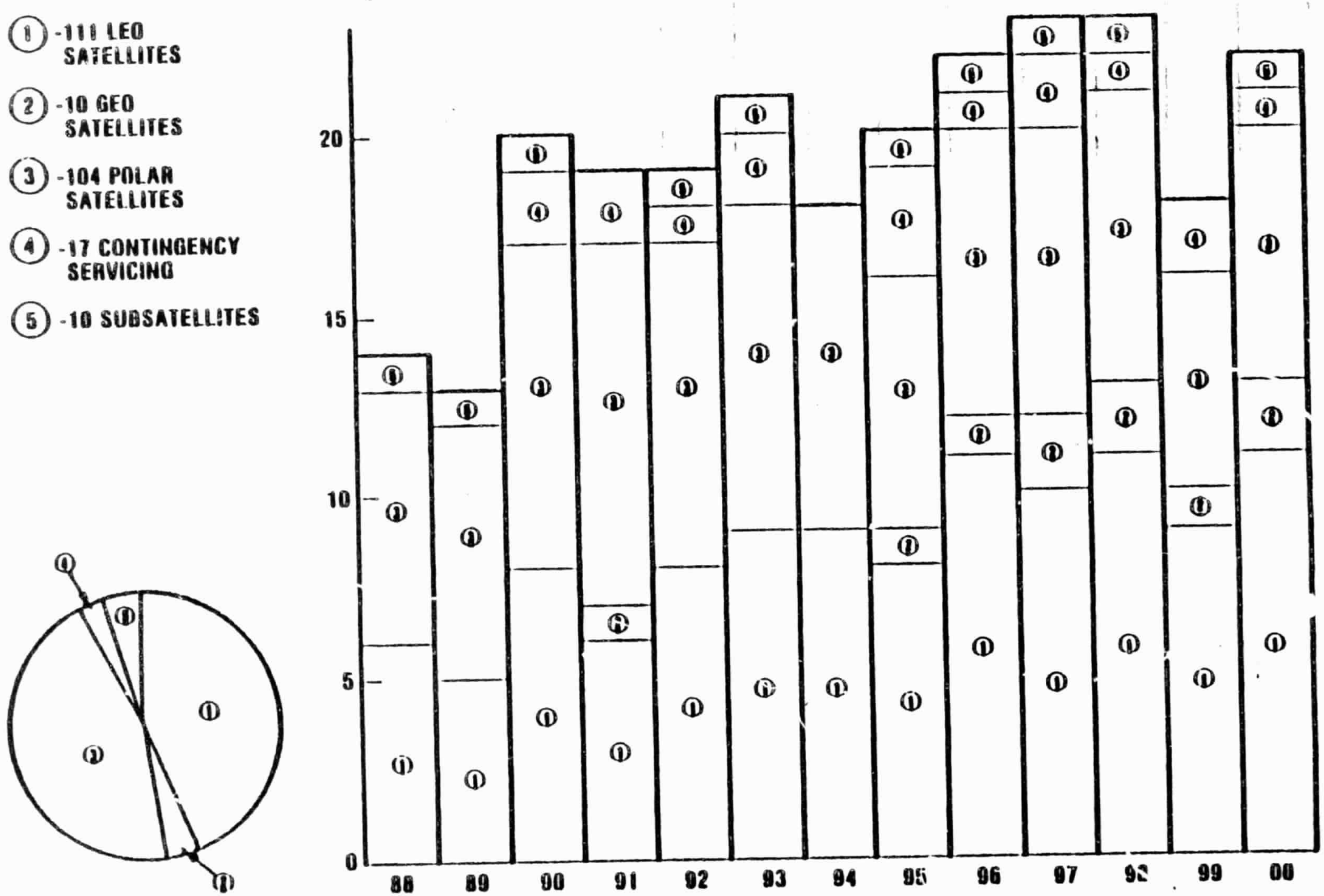


HIGH TMS MISSION MODEL

The high TMS mission model, as described previously, may be divided into the five reference missions. The facing chart shows how the nominal TMS mission model breaks down by year with these missions. A pie-chart in the lower left-hand corner shows the relative proportion of each type of mission.

In this model, the number of LEO TMS engagements from KSC grows, but due to the relative ease of co-manifesting LEO TMS engagements at low inclinations, the ratio of KSC/WTR multipurpose/multifunction TMS missions does not grow substantially.

HIGH TMS MISSION MODEL
(252 TOTAL MISSIONS)



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SPACE-BASED TMS ISSUES (TECHNICAL)

If it is desirable to space-base the TMS, then several new technical issues arise which must be resolved. The two basic issues are very briefly discussed below.

The issue of exactly where to space-base the TMS must be answered. From the plot of TMS payload altitude vs. inclination shown previously, the obvious solution is to base the TMS in a 28.5° inclination orbit. In this orbit, various options then exist to accommodate the space-based TMS. These include leaving the TMS in orbit between missions as a free flyer; adding a larger fuel tanker from which the TMS could top off its tanks before flying a mission, and extending the TMS lifetime on orbit; adding in orbit, besides the full tanker, a "primitive warehouse" to provide on-orbit storage of spare parts, TMS mission kits, and TMS battery rechargers, as well as extra TMS fuel; making the TMS compatible with a later LEO space platform which could provide all the services and capabilities of the aforementioned options.

The second, but most technically difficult problem is the TMS phase change capability issue caused by nodal precession between orbits of different parameters. As time goes on, two payloads, orbits/planes, although deployed at the same time into a single inclination (although at different altitudes) will separate. To perform a multipurpose TMS mission, this issue must be resolved. The direct answer is to take the brute force approach; provide the TMS enough fuel to make a direct propulsive burn between the planes. This method is wasteful of fuel and drives TMS transportation costs up.

A second solution, instead of moving the TMS directly to the payload, is to drop it into a lower orbit with a higher nodal precession rate, and allow this to accomplish the required phase change. Similarly, by the use of judicious mission planning to time the TMS missions, it would be possible for the space-based TMS to merely wait on orbit until the desired orbital planes line up.

Finally, if an expected trend develops to deploy payloads only into a few preferred orbital planes with the same nodal precession rate (deploying payloads along the orbit like "beads on a string"), in order to facilitate payload access to TMS services, then this problem goes away entirely.

For these issues, there seem to be no unsolvable technical problems, although a more detailed look is required to better define the solutions.

SPACE-BASED
TMS ISSUES (TECHNICAL)

WHERE?

- MANY SOLUTIONS (28.5^{0})
  - TANKER (FUEL)
  - PRIMITIVE WAREHOUSE
  - SPACE PLATFORM
  - FREE FLYER

PHASE CHANGE (NODAL PRECESSION)

- SEVERAL SOLUTIONS
  - PROPULSIVE BURN (BRUTE FORCE ANSWER)
  - PHASING ORBIT
  - MISSION PLANNING/TIMING (WAIT FOR PLANES TO LINE UP)
  - ESTABLISH STANDARD ORBITAL PLANE(S) ("BEADS ON A STRING")

NO UNSOLVABLE TECHNICAL ISSUES

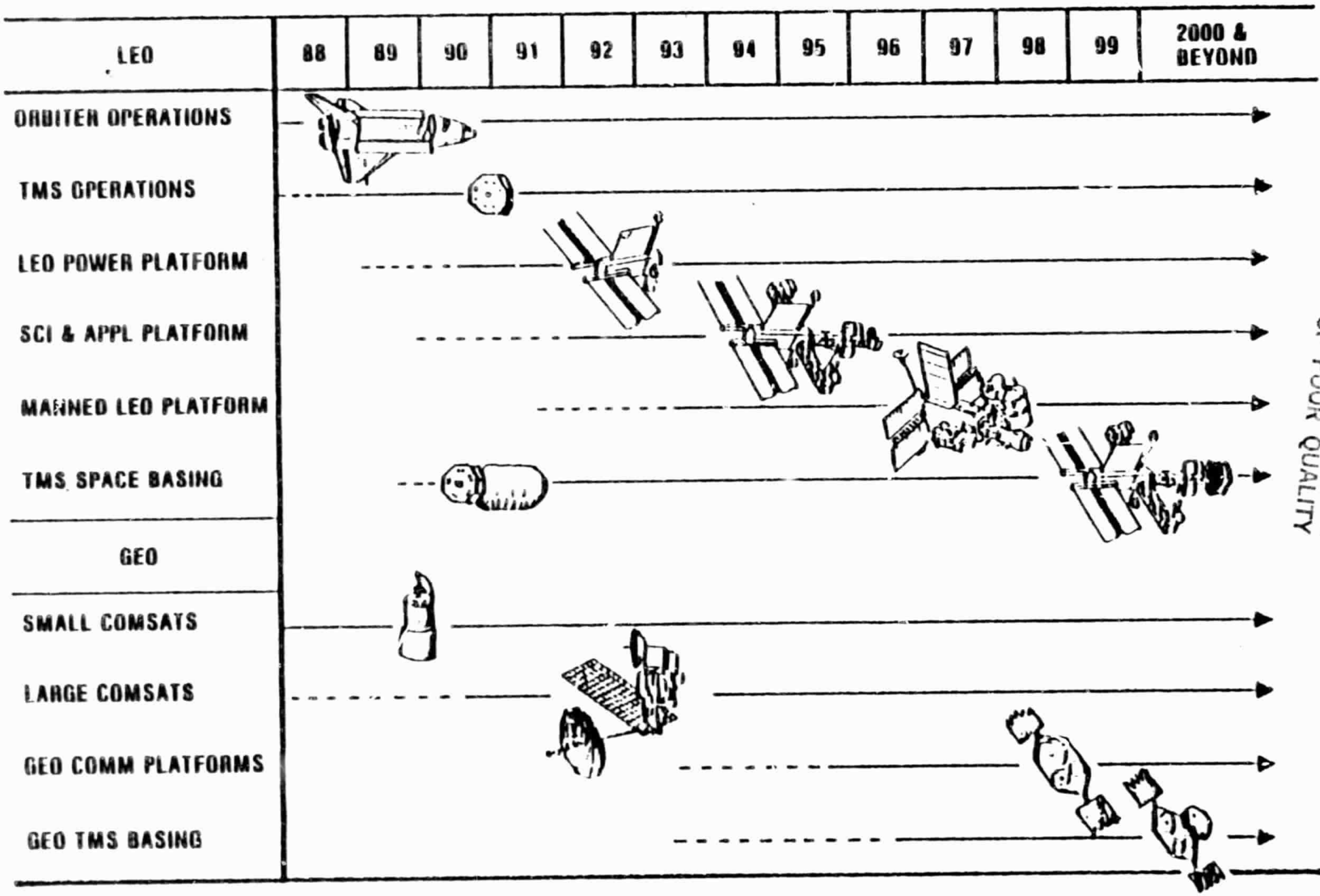
- MORE DETAILED LOOK REQUIRED

EVOLUTION INTO TMS SPACE BASING

Over the next two decades, as the TMS becomes operational and the scope of space operations expand, the TMS will play an important role in routine space operations. Along with orbiter operations, TMS operations in LEO will become routine, possible growing into an early space-based mode centered around on-orbit storage of TMS propellant. Later, it is expected that LEO space platforms will be placed in orbit beginning with a simple power platform and eventually evolving into a manned LEO platform. Ultimately, the TMS will become an essential part of space platform operations, extending its utility to many areas, while using the platform to support space-based TMS missions.

Similarly, in GEO, satellites are expected to continue the present trend to grow in size and capability. To support this large concentration of capital and capability, unmanned servicing through the TMS will be required. Once in GEO, the TMS may use the GEO platform to provide the services of a space-base to the TMS.

EVOLUTION INTO TMS SPACE BASING



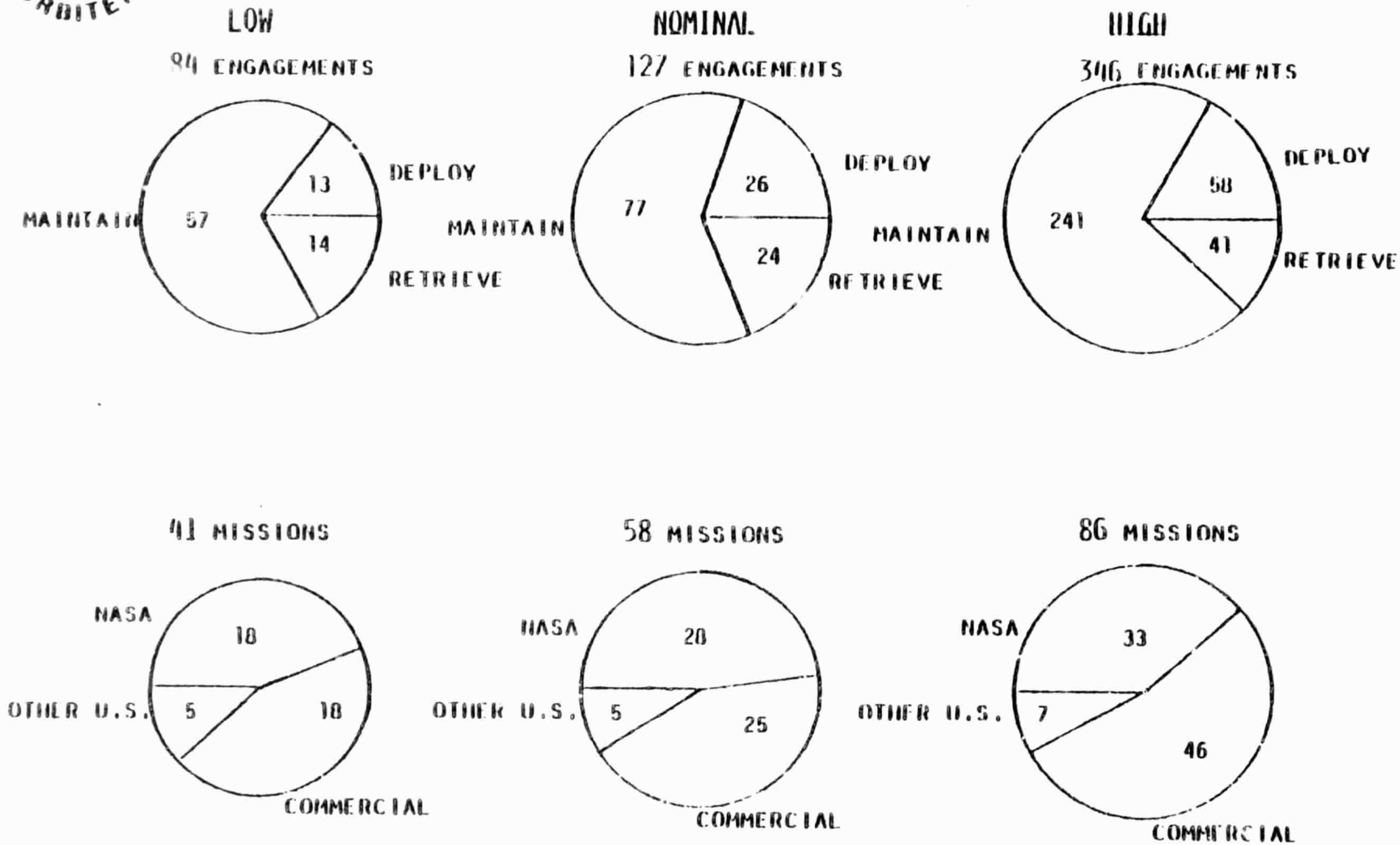
92SSV126265

SPACE-BASED TMS MODEL

If only those missions of interest to the 28.5°, LEO space-based TMS are examined, then from the 3 TMS models discussed earlier, the results shown on the facing page are derived. In all models, the preponderance of engagements lies in the routine maintenance or servicing of payloads. These arise from the requirements to support the postulated commercial materials processing ventures, or in the routine servicing of large astronomical observatories placed in LEO.

SPACE SHUTTLE ORBITER

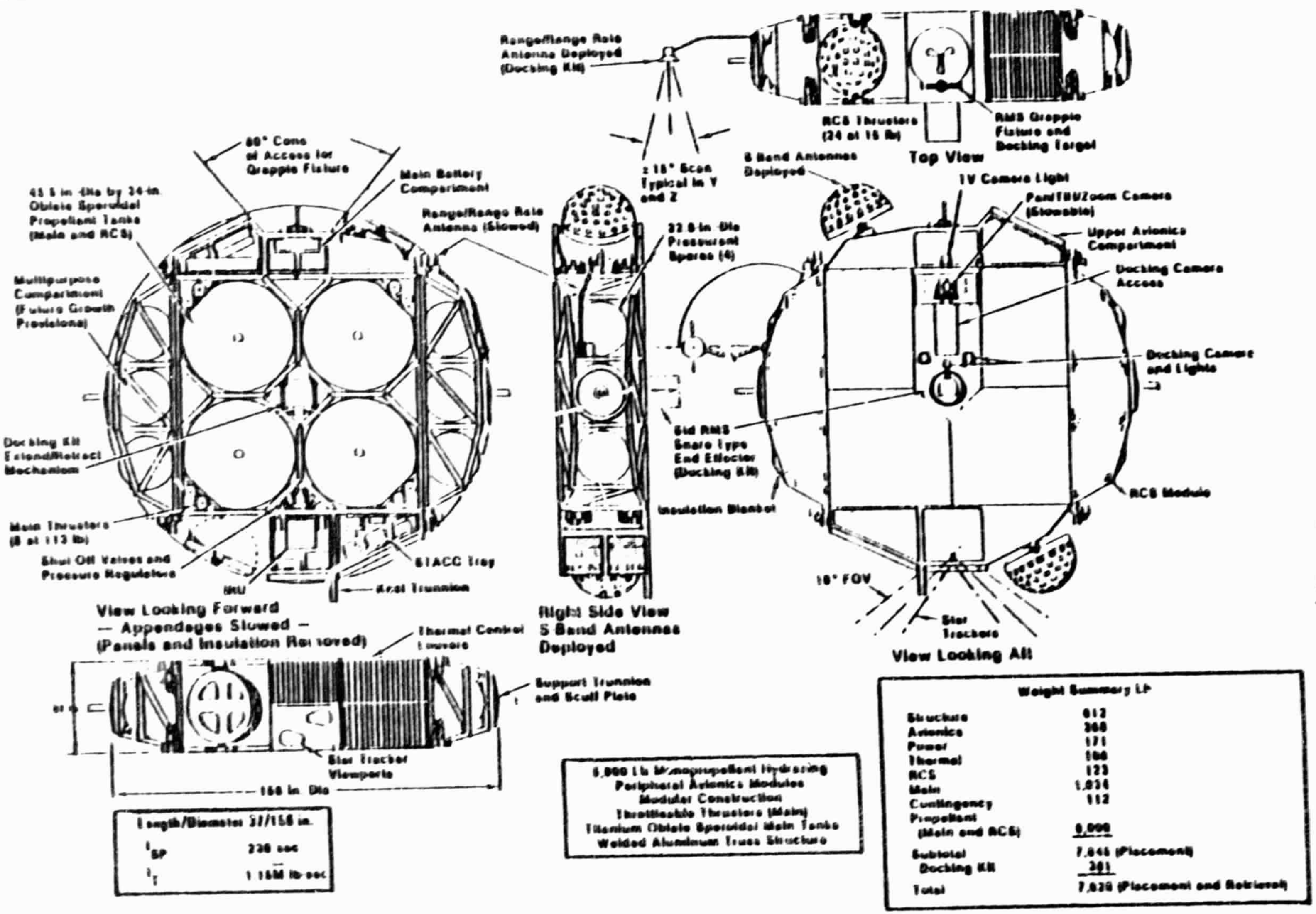
SPACE-BASED TMS MODEL FOR 28.5° ORBIT



BASELINE TMS CONFIGURATION

The facing page illustrates the baseline TMS configuration utilized in this study. It is the Vought Phase 'A' configuration, performed for NASA/MSFC under NASA Contract NAS8-33903 from June 1980 through May 1982. The reader is directed to the Vol. II "Technical Report" for further details.

BASELINE TMS CONFIGURATION



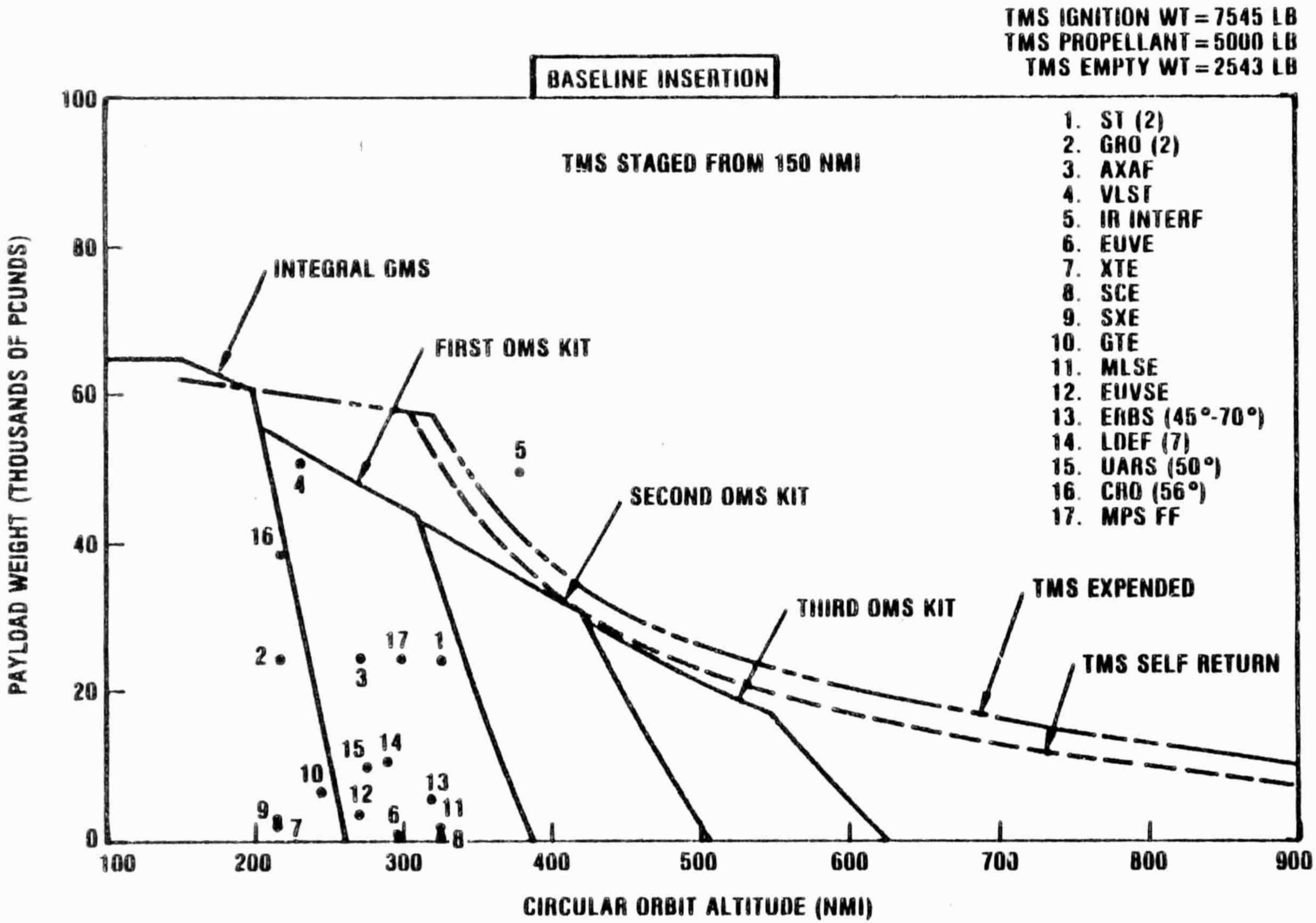
TMS PERFORMANCE AT 28.5° ORBIT INCLINATION

The chart shows which satellites may be deployed from the eastern test range using a baseline launch trajectory and OMS kits or a TMS. The TMS can deploy all the payloads which would have required the addition of OMS kits and, in fact, heavier payloads at the lower altitudes. The infrared interferometer requires deployment of the TMS at 200 nm.

The TMS is assumed to be a minimal system (2545 pounds) without docking kit and to stage from the orbiter at 150 nautical miles altitude except as noted for the infrared interferometer. The necessity to remove propellant to remain within the weight capability of the orbiter causes the sloping left hand portion of the TMS delivery curve. The right portion of the curve divides depending whether the entire 5,000 pound propellant capacity has been used to deploy a payload, or whether a sufficient amount of propellant has been reserved to return the TMS to a 150 nautical mile circular orbit.

The specific impulse of the TMS in these calculations is 230 seconds.

KENNEDY SPACE CENTER SATELLITES
28.5° INCLINATION EXCEPT AS NOTED



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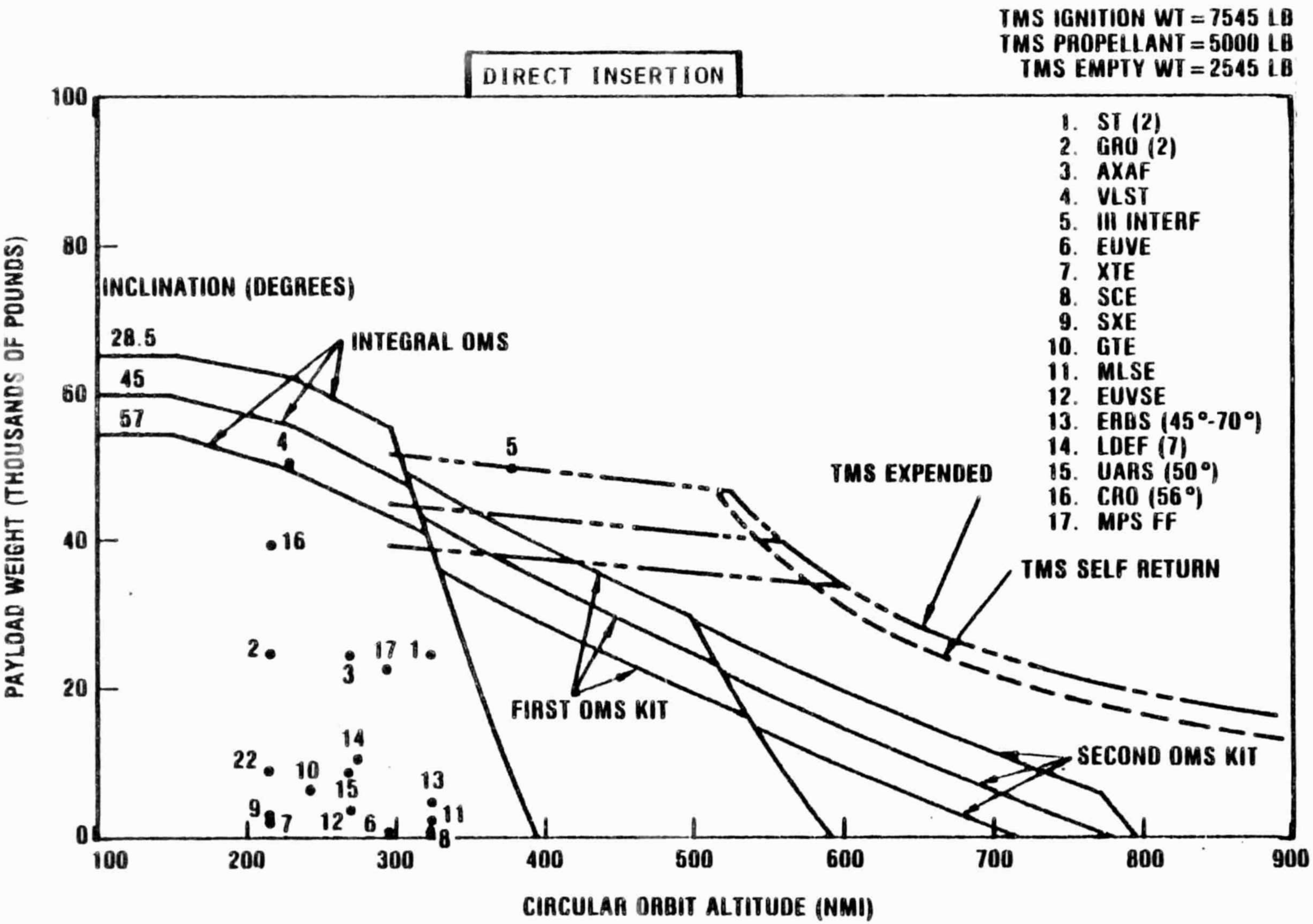
TMS PERFORMANCE AT ETR, WITH ORBITER AT HIGH ALTITUDE

This chart is similar to the preceding chart, but shows the effect of direct high altitude orbiter insertion on payload delivery capabilities. The direct insertion capabilities have been obtained from a NASA/JSC level II change request document. It may be seen that direct insertion can deliver all the payloads that would have required an OMS kit under the baseline insertion condition, except for the infrared interferometer.

When TMS is combined with direct insertion, it is more efficient to raise the staging to 300 nautical miles. The infrared interferometer is then within TMS capabilities.

KENNEDY SPACE CENTER SATELLITES
28.5° INCLINATION EXCEPT AS NOTED

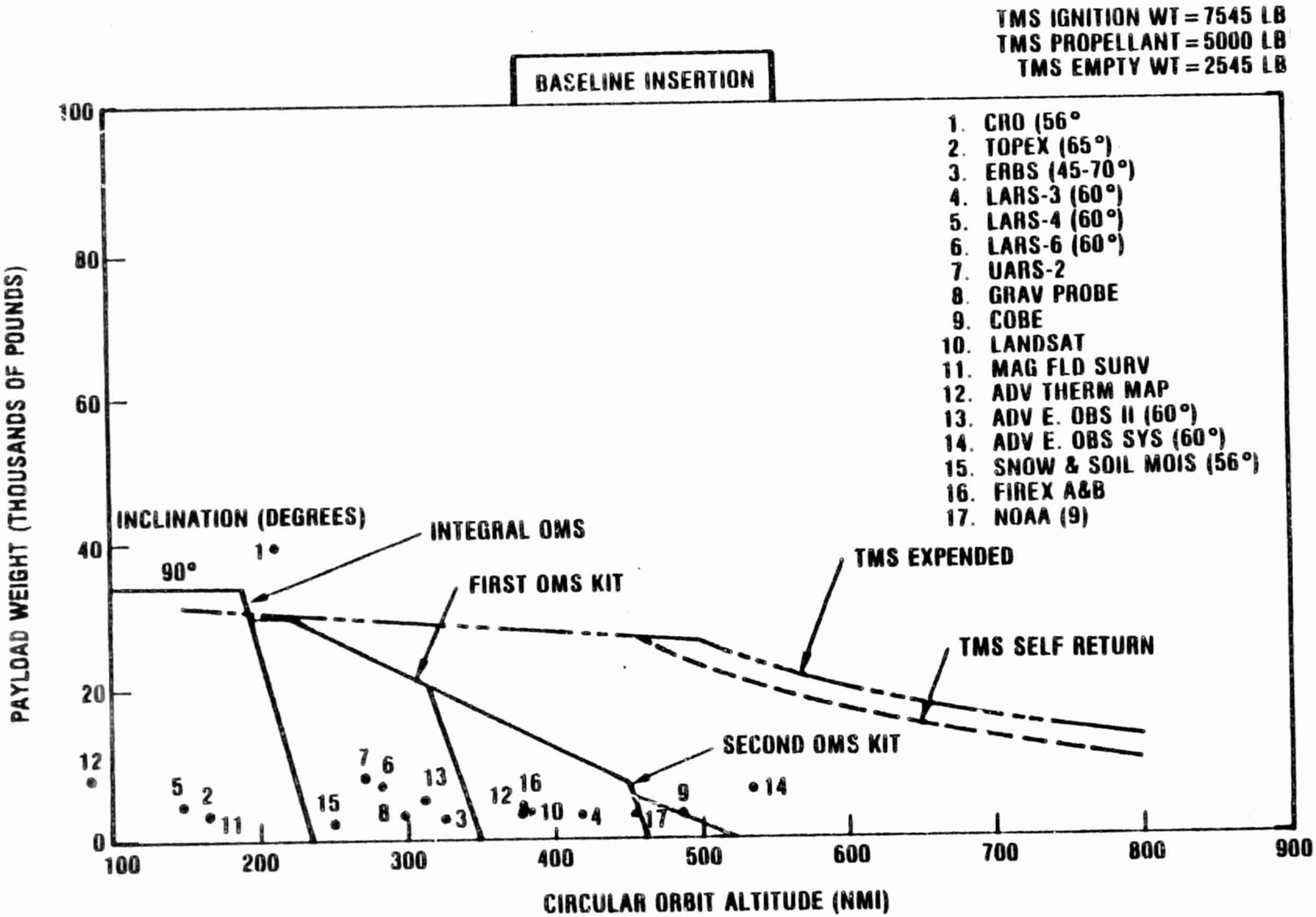


92SSV126263-1

TMS PERFORMANCE AT WTR

The baseline TMS/Orbiter launch performance is shown for the 90 to 98 degree inclination orbits from the western test range. The TMS can perform all missions which would have required OMS kits, and has significantly better high altitude performance.

WESTERN TEST RANGE SATELLITES
90 TO 98 ° INCLINATION EXCEPT AS NOTED

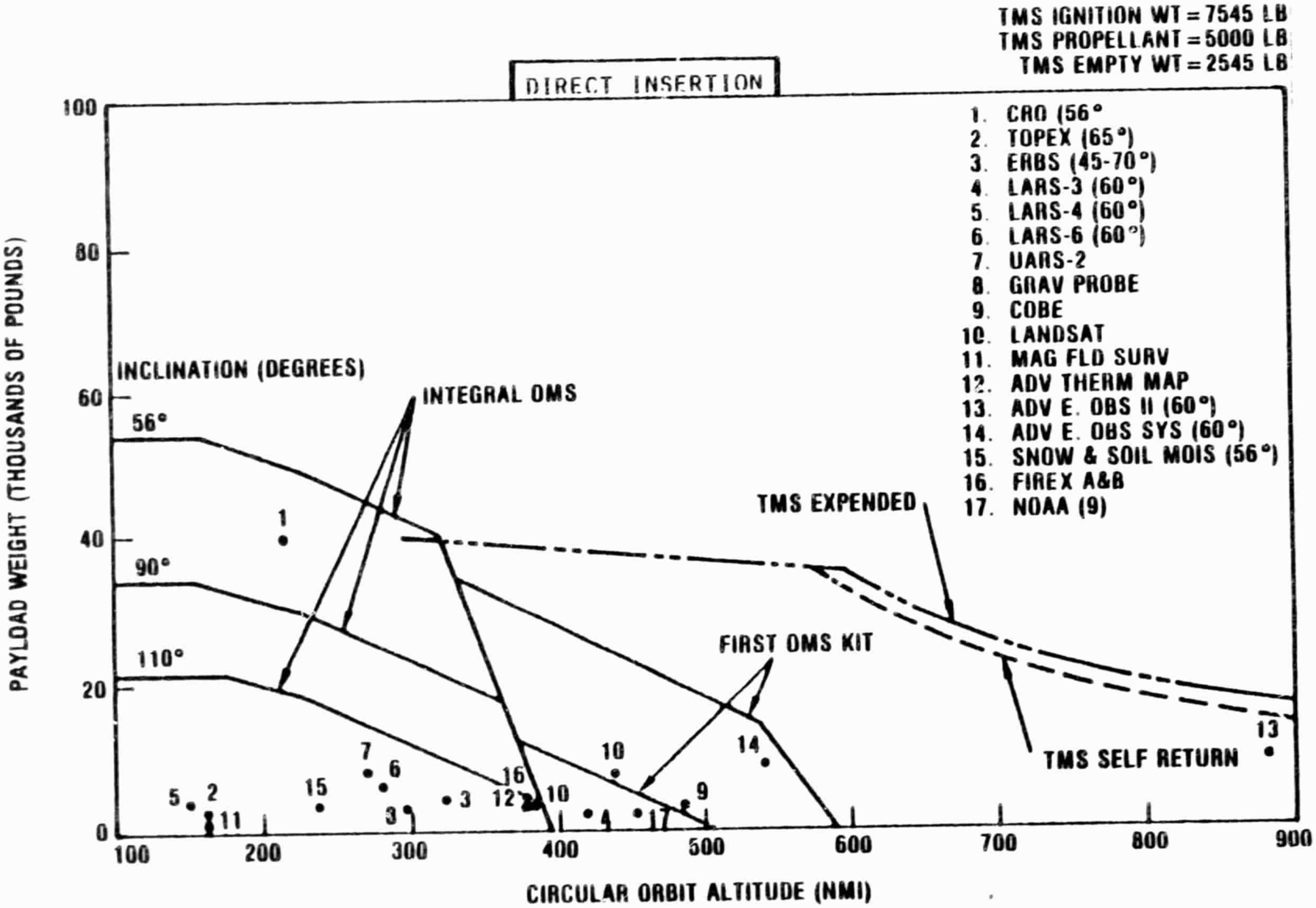


92SSV126261-1

TMS PERFORMANCE AT WTR, WITH ORBITER AT HIGH ALTITUDE

The effect of a direct high altitude orbiter insertion ascent trajectory on payload delivery capabilities is shown. Direct insertion will obviate the need for the OMS kit for the satellites below 400 nautical miles. Above this altitude, an OMS kit or other delivery system would be required. The TMS, staged from a 56 degree inclination orbit at 300 nautical miles, would be able to perform all satellite delivery missions shown.

WESTERN TEST RANGE SATELLITES
90 TO 98° INCLINATION EXCEPT AS NOTED

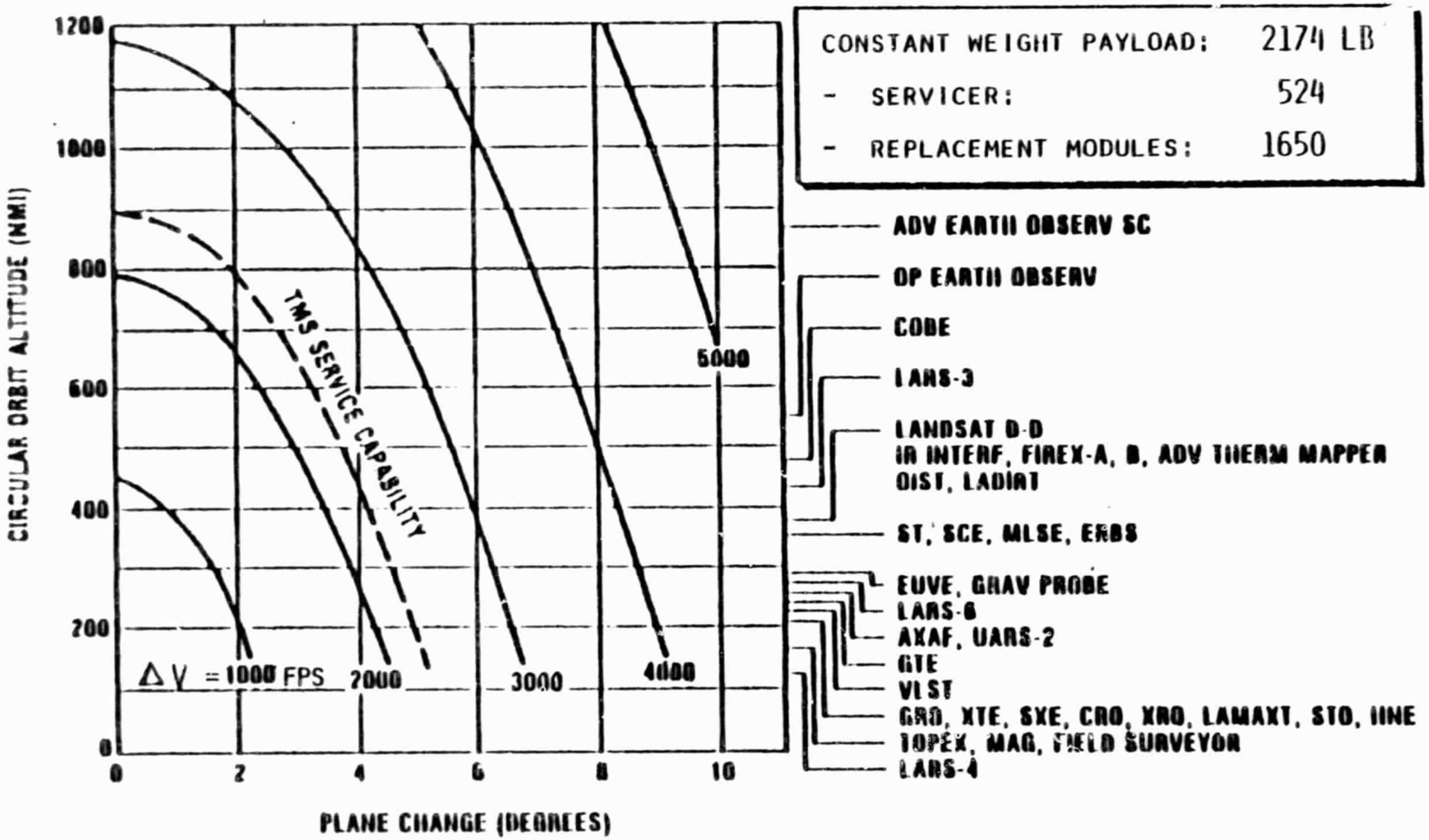


92SSV126262-1

TMS PERFORMANCE - PLANE CHANGE VERSUS ALTITUDE

The chart shows the incremental velocity required to ascend from a 150 nautical mile orbit to another circular orbit, combined with a plane change requirement. The ΔV capability of a monopropellant TMS for a round trip service mission is indicated. Along the right hand side of the grid the altitude locations of various satellites are shown for reference. For example, the TMS would be able to service the Landsat D after making a four degree plane change. A service mission may be viewed more generally as a round trip payload mission for the TMS.

PLANE CHANGE EFFECT ON TMS SERVICE CAPABILITY



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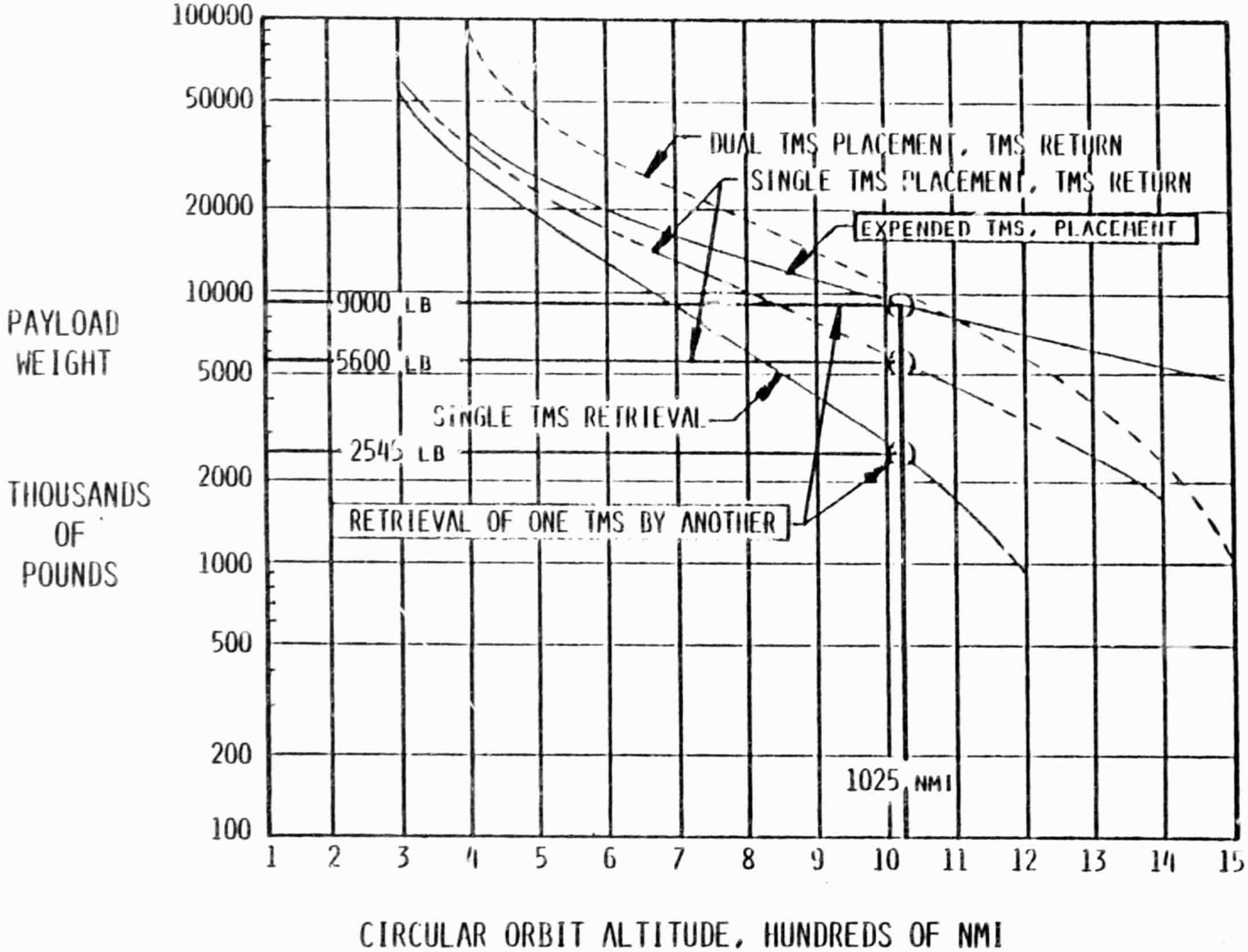
TMS RETRIEVAL BY ANOTHER TMS IMPROVES PLACEMENT CAPABILITY

Rockwell has identified a procedure for increasing payload placement capability of the baseline TMS.

As shown in the chart, the TMS can deliver 5600 pounds to 1025 nm and return to 150 nm. It can also deliver 9000 pounds to the same altitude, depleting its fuel, and the TMS would normally be expended. However, this TMS can be retrieved by a second TMS, thus substantially reducing the cost of the payload delivery mission. Also applies to heavier payloads below 1025 nm.

The dual TMS, which includes the Vought add-on tank module, could perform the same mission, as shown, but this procedure would be available in advance of tank module development.

TMS RETRIEVAL BY ANOTHER TMS IMPROVES PLACEMENT CAPABILITY



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SPACE BASED, GROUND REFUELED TMS

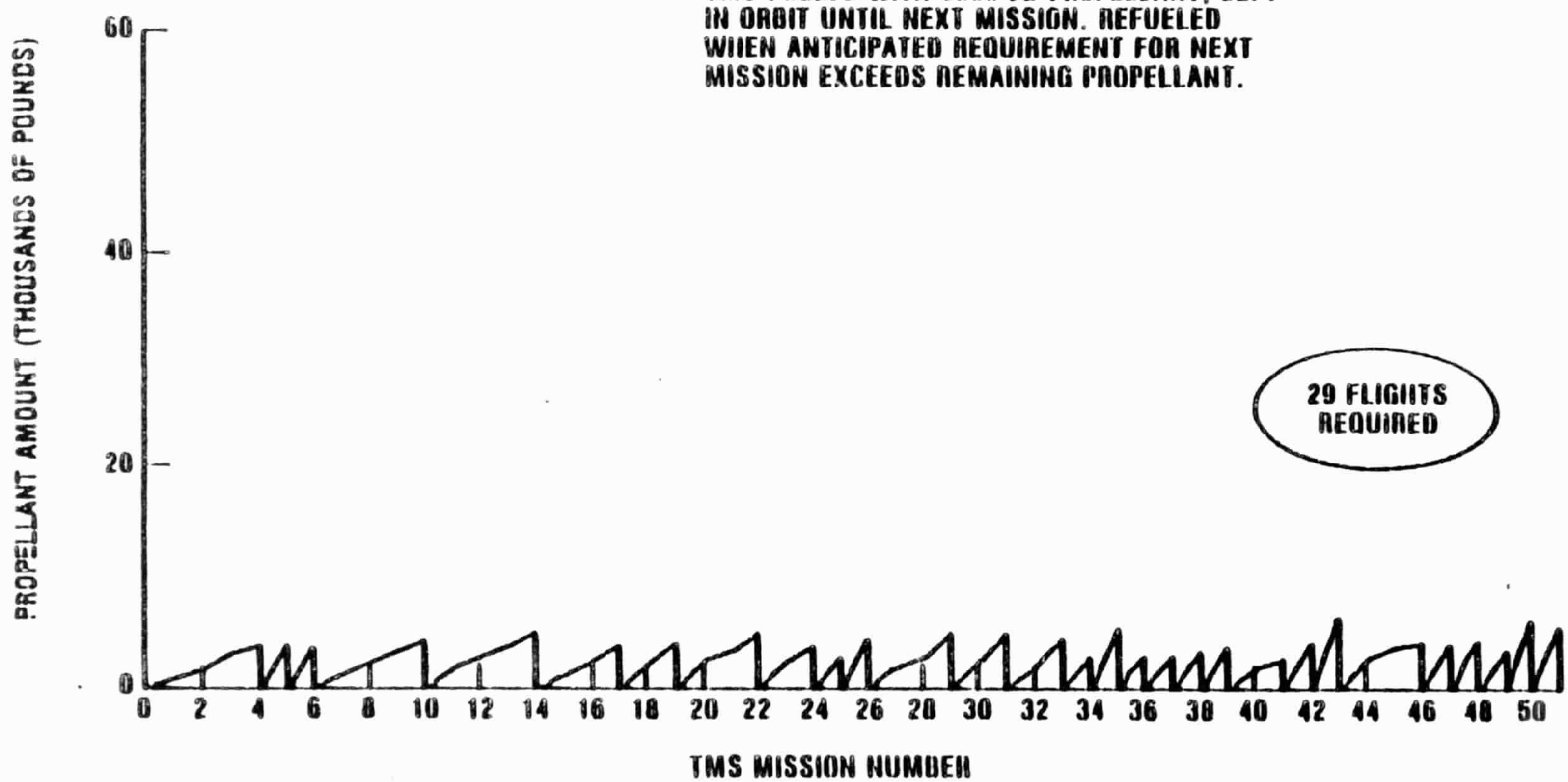
The amount of storable bipropellant which would be used to perform 51 low earth orbit missions at 28.5 degrees inclination is shown. The scenario for this case assumes a 5000 pound propellant capacity TMS is placed in a 250 nautical mile orbit. The missions are performed until the remaining propellant is insufficient for the next mission. It is then recovered for ground-refueling and replaced with another TMS. Twenty-nine shuttle launches are required to perform the 51 missions.

CUMULATIVE PROPELLANT USAGE (GROUND REFUELING)

GROUND REFUELING

MISSIONS STAGED FROM 250 MNI, 28.5° ORBIT
STORABLE BIPROPELLANT, I_{SP}=326 SEC

TMS FUELED WITH 5000 LB PROPELLANT, LEFT IN ORBIT UNTIL NEXT MISSION. REFUELED WHEN ANTICIPATED REQUIREMENT FOR NEXT MISSION EXCEEDS REMAINING PROPELLANT.



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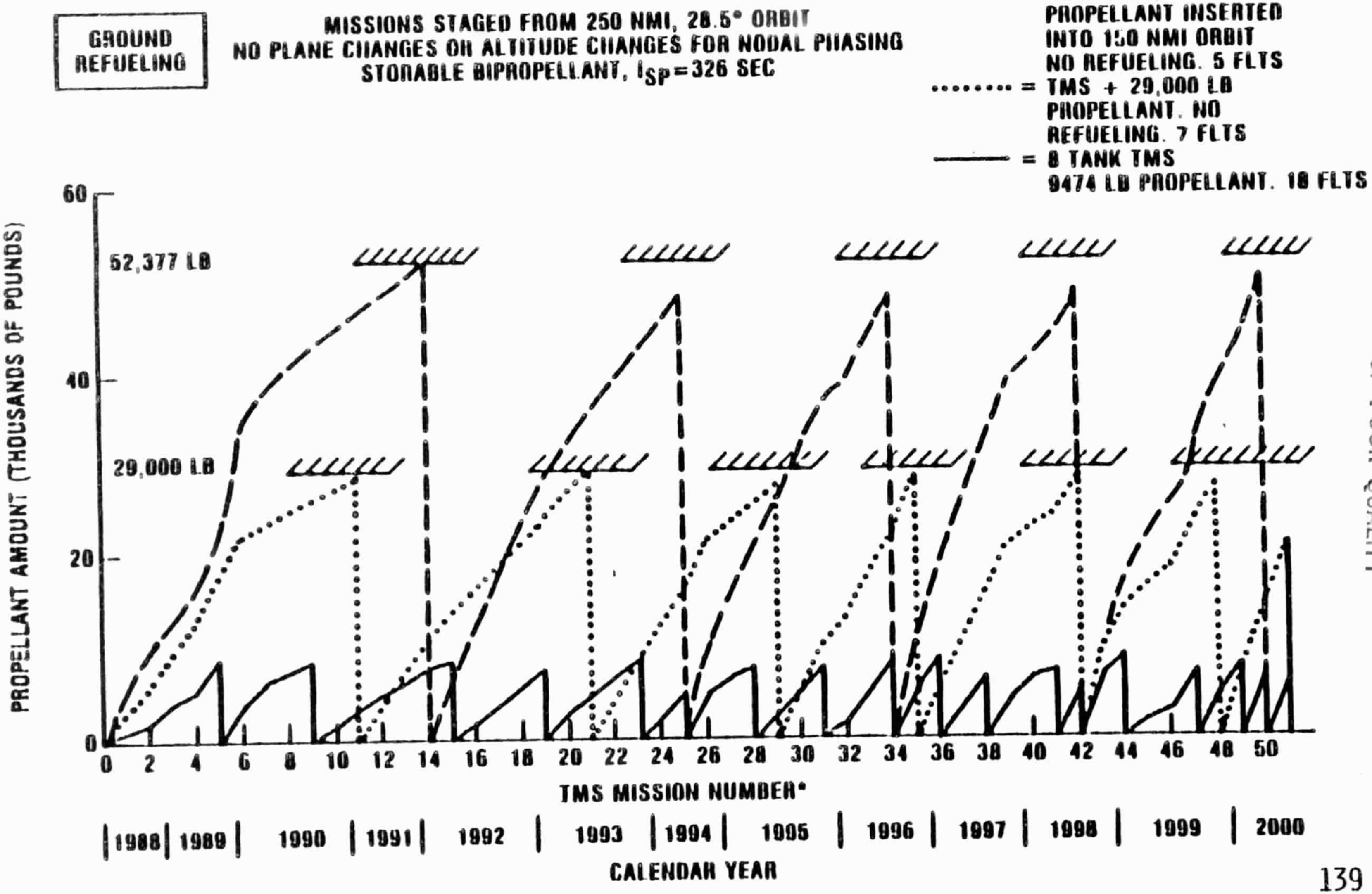
The amount of storable bipropellant utilized to perform 51 low earth orbit missions at 28.5 degrees inclination, as described in the optimized baseline mission model, is given. The three sets of cumulative propellant usage curves correspond to three sizes of add-on tank modules for the ground refueled TMS. The highest curve, with the fewest number of launches, is the result of using a 63000 pound tank module and TMS containing 55000 pounds of fuel to perform the missions. The orbiter delivers this TMS to a 150 nautical mile orbit from which it propels itself into a 250 nautical mile storage orbit. After self-delivery, it has 52377 pounds of fuel for TMS missions. A propulsion system specific impulse of 326 seconds has been used.

The TMS missions are assumed to begin with shuttle delivery of a payload to the TMS. The TMS then propels the payload either to a higher or lower orbit with Hohmann-type maneuvers. No plane changes or altitude changes solely for the purpose of nodal phasing have been included. The TMS then either returns itself or a retrieved satellite to the storage orbit via a 150 nautical mile phasing orbit.

The other two sets of curves are for a TMS with 25000 pounds of fuel and for the Vought "Dual-TMS" containing 9474 pounds of fuel. The ground rules of operation are the same as for the heavier TMS.

The TMS with 55000 pounds fuel requires five launches to complete 51 missions. The order of the missions within each year was arbitrarily chosen. The 25000 pound TMS requires 7 replacement launches and the "Dual-TMS", 19 launches.

CUMULATIVE PROPELLANT USAGE (GROUND REFUELING)



92SSV126259

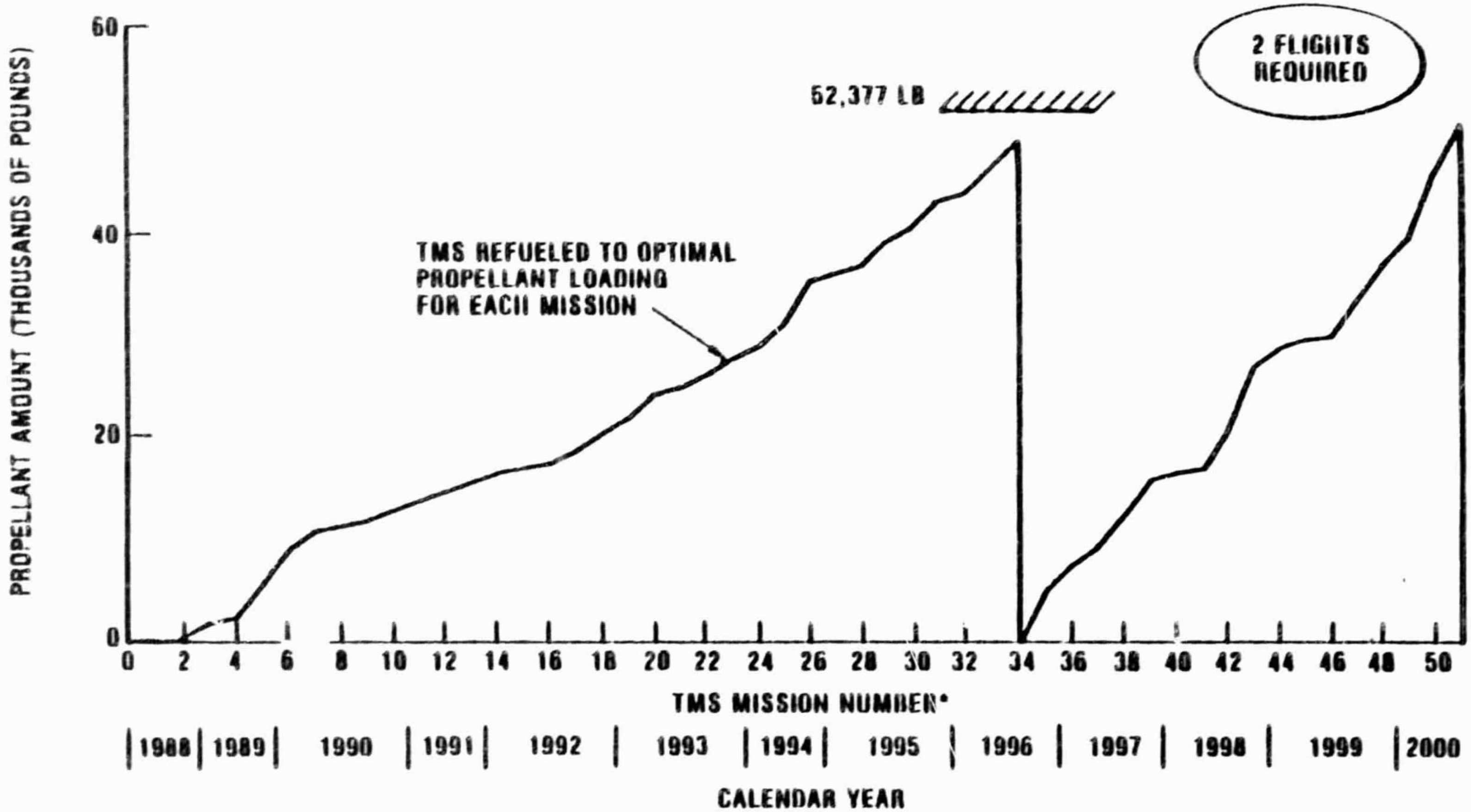
SPACE BASED, ON ORBIT REFUELED TMS

The amount of fuel which would be used by a bipropellant TMS of 5,000 pound propellant capacity that refuels itself from an orbiting 50,000 pound tanker is shown. The TMS would take aboard only enough fuel for each mission. Two shuttle launches would be required to launch the tankers to support the 51 reference missions.

CUMULATIVE PROPELLANT USAGE (ON-ORBIT REFUELING)

ON-ORBIT REFUELING

MISSIONS STAGED FROM 250 NMI, 28.5° ORBIT
NO PLANE CHANGES OR ALTITUDE CHANGES FOR NODAL PHASING
STORABLE BIPROPELLANT, $I_{SP} = 326$ SEC



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TMS FLEET SIZE
LOW MODEL

For the TMS low mission model, using an assumed maximum TMS flight rate of 7 TMS missions per year, a total of 3 vehicles are required.

One TMS test flight is included in 1987, and one TMS mission to GEO for a demonstration of GEO servicing is included.

At a total of 50 missions per TMS vehicle, no extra TMS vehicles are needed beyond the 3 shown.

TMS FLEET SIZE
LOW MODEL

3 TMS VEHICLES REQUIRED

	87	88	89	90	91	92	93	94	95	96	97	98	99	100	TOTAL MISIONS
TMS MISSIONS		6	3	9	6	8	8	9	7	8	6	8	6	9	
TEST FLIGHTS	1														
TMS VEHICLES															
1	1	6	3	7	6	5	4	5	4	5	4*				50*
2				2	-	3	4	4	3	3	2	7	6	7	41
3												1	-	2	3

*VEHICLE IS EXPENDED ON FLIGHT TO GEO

TMS FLEET SIZE
NOMINAL MODEL

In the TMS nominal mission model, using a maximum TMS flight rate of 7 TMS missions per year, a total of 10 TMS vehicles are required, at a flight life of 25.

The vast majority of vehicles (8) is expended at GEO in support of GEO servicing missions. 3 TMS test flights are included in 1987-1988. Using a maximum achievable TMS flight rate of 7 TMS flights per year per vehicle, and spreading the TMS lifetimes to be as close as possible before the TMS is expended, it is found a lifetime of about 25 missions yields the smallest fleet size of 10 vehicles. For a 30-flight life, fleet size drops to 8; 50-flight life: 6 vehicles required; 100-flight life: fleet size drops to 4.

TMS FLEET SIZE
NOMINAL MODEL

10 TMS VEHICLES REQUIRED AT 25-FLIGHT LIFE **

	87	88	89	90	91	92	93	94	95	96	97	98	99	100	TOTAL MISSIONS
TMS MISSIONS		12	12	18	17	18	20	15	18	17	19	17	17	18	
TEST FLIGHTS	1	2													
TMS VEHICLES															
1	1	4	3	4	3*										15*
2		4	3	3	4	3	4	-	-	-	2*				23*
3		4	3	4	3	4	3	3	1*						25
4		2	3	4	3	3	4	3	2	1*					25*
5				3	4	4	3	3	3	4	1*				25*
6						4	4	3	4	3	4	3*			25*
7							2	3	4	3	4	4	5*		25*
8									3	4	4	4	5	5*	25*
9									1	2	4	6	6	6	25
10													1	7	8
															221

** 10 VEHICLES @ 25-FLIGHT LIFE
8 VEHICLES @ 30 FLIGHT LIFE
6 VEHICLES @ 50 FLIGHT LIFE
4 VEHICLES @ 100 FLIGHT LIFE

* VEHICLE IS EXPENDED ON FLIGHT TO GEO

TMS FLEET SIZE
HIGH MODEL

In the TMS high model, using a maximum TMS flight rate of 7 missions per year, a total of 12 TMS vehicles are required.

Again, as in the nominal mission model, the majority of TMS vehicles (10) is expended at GEO in support of GEO servicing missions. 3 TMS test flights are included in 1987-1988. Using 7 as the maximum yearly flight rate per TMS, and spreading the missions between TMS vehicles to try to keep the TMS lifetimes equal at wearout, a lifetime of 30 flights indicates the minimum fleet size of 12. Particularly in this model, the expenditure of TMS vehicles at GEO drives the total missions achieved, before TMS expenditure, down in the later years.

SPACE SHUTTLE ORBITER

TMS FLEET SIZE
HIGH MODEL

12 TMS VEHICLES REQUIRED

	87	88	89	90	91	92	93	94	95	96	97	96	99	100	TOTAL MISSIONS
TMS MISSIONS		14	13	20	19	19	21	18	20	22	23	23	18	22	
TMS TEST FLIGHTS	1	2													
TMS VEHICLES															
1	1	7	7	7	7*										29*
2		7	3	3	3	4	3	3	3*						30*
3		2	3	4	3	4	3	4	4	3*					30*
4				3	3	5	7	3	3	3	3*				30*
5				3	3	6	7	3	3	3	2*				30*
6							1	2	4	6	7	7*			27*
7								3	3	7	7	7*			27*
8											4	7	7*		18*
9												2	7	7*	16*
10													2	7*	9*
11													2	7	9
12														1	1

TECHNICAL DISCUSSION - TASK 4.2

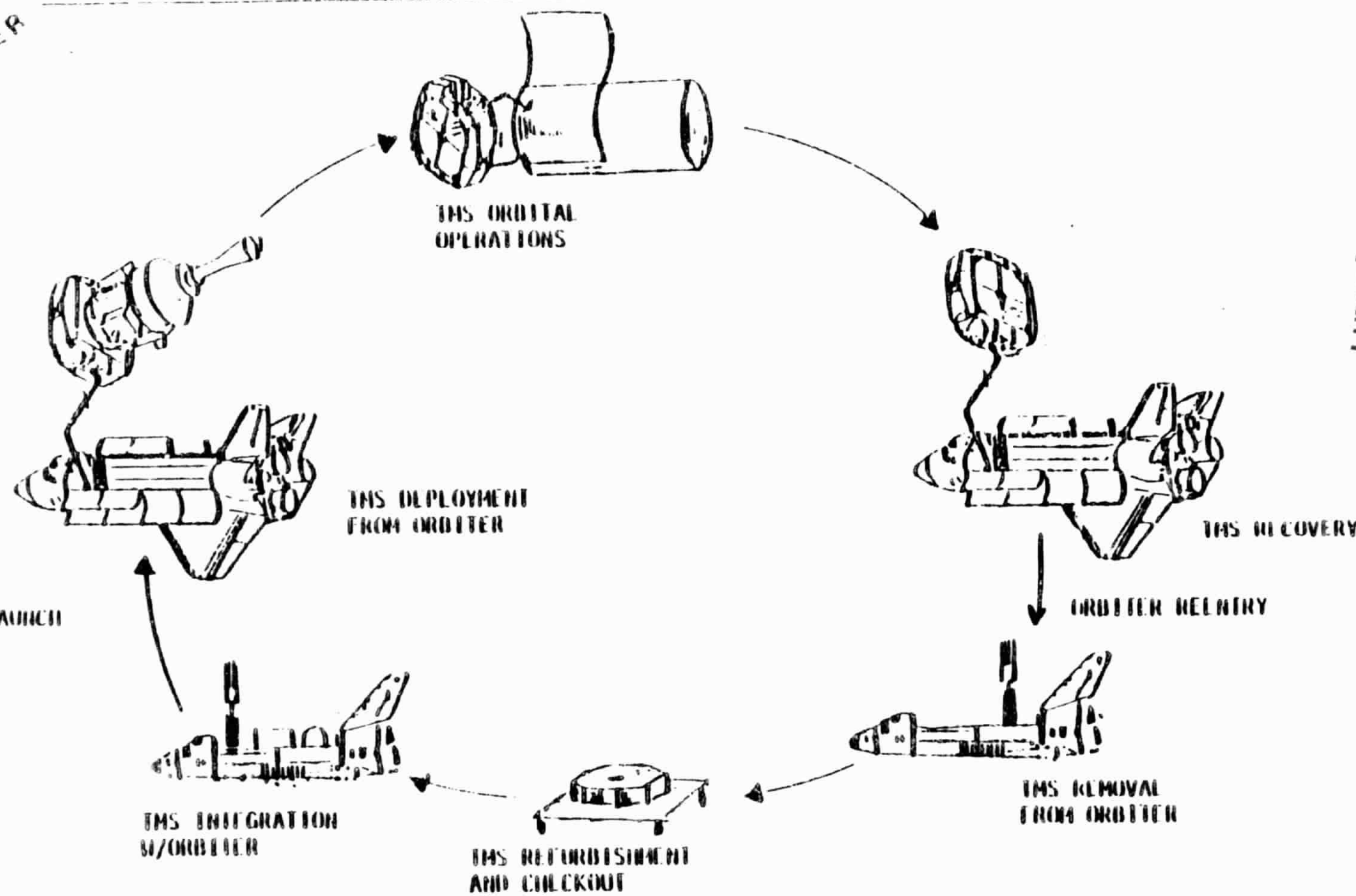
TMS/PAYLOAD/ORBITER SYSTEMS INTEGRATION

TMS OPERATIONS FLOW

The facing chart illustrates a typical TMS mission cycle, which includes TMS deployment from the orbiter, payload mating, TMS flight operations, recovery into the orbiter, removal from the orbiter after landing, ground refurbishment and checkout, reintegration with a space shuttle, and launch for a second mission.

It should be pointed out that this cycle is not tied to similar operations flows with the shuttle orbiter. In a limited space basing mode, even without on orbit refueling, the TMS need not be recovered on the same orbiter that deployed it, nor does it have to be launched on the same orbiter that retrieved it. This essentially uncouples the TMS operations flow from the orbiter operations flow.

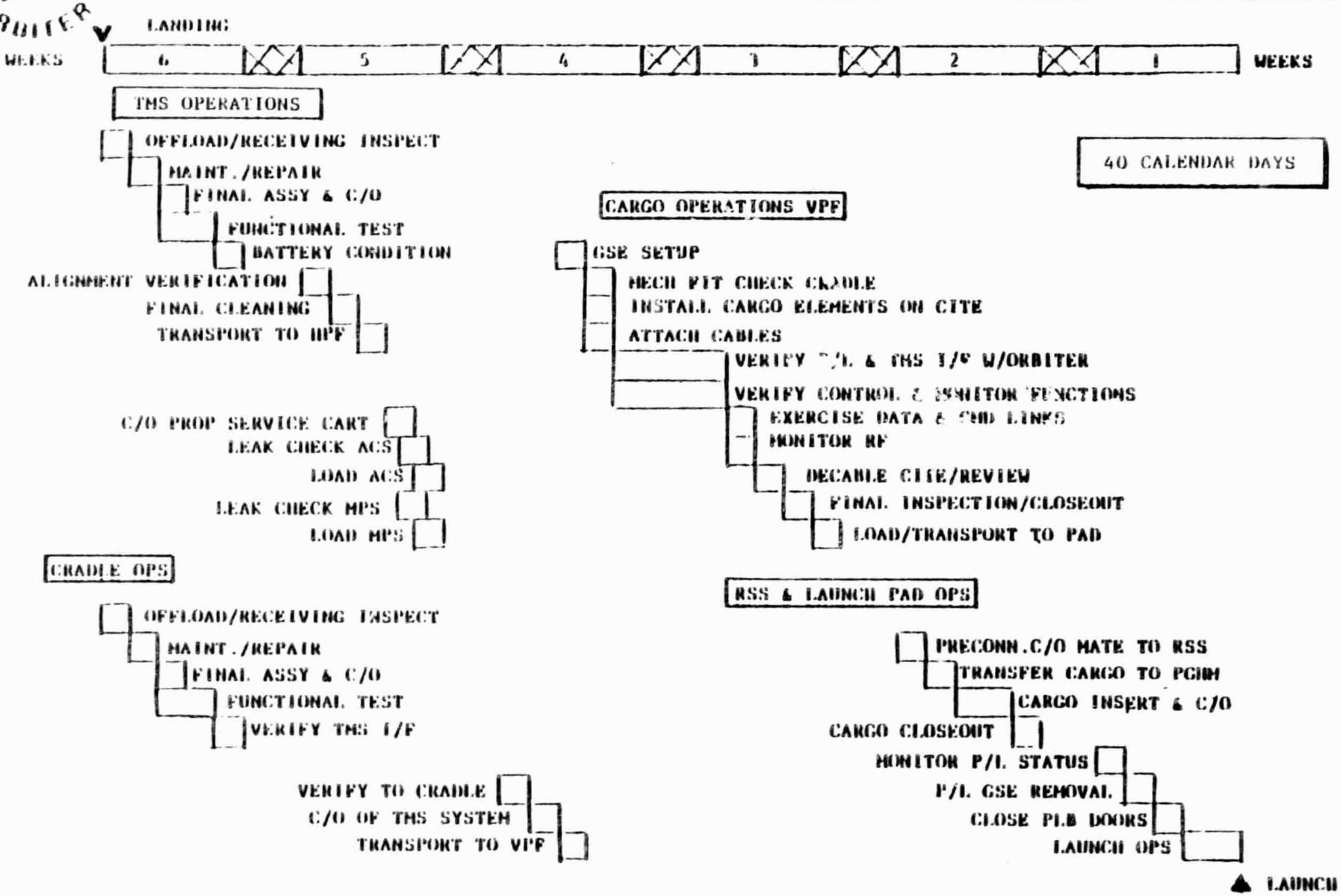
TMS OPERATIONS FLOW



TMS MISSION GROUND TURNAROUND TIME

The facing chart indicates the TMS ground turnaround time between missions with mature STS operations. Key to this reduction is reducing the cargo integration times required for an STS launch. From landing to launch, 40 calendar days were estimated.

THS TURNAROUND TIME, 40 DAYS

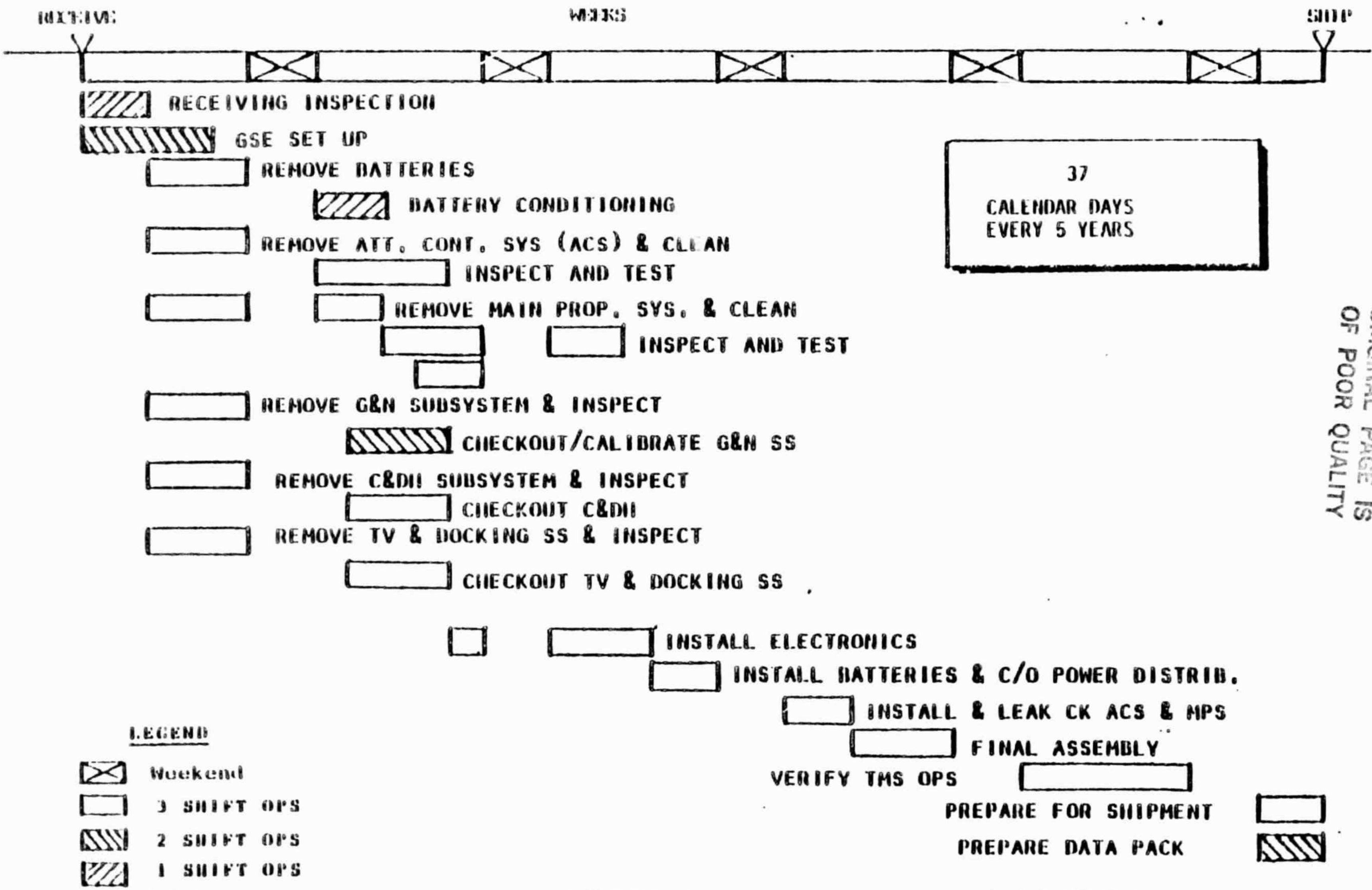


TMS REFURBISHMENT TIMELINE

The TMS will be returned to the manufacturing facility for refurbishment. Assuming a 10 year, 30 flight life, major refurbishment may be required but once. Selected subsystems will be removed from the primary TMS structure and transported to the maintenance and test area. Purpose of the overhaul will be to clean, inspect, repair, and test the subsystems in order to ensure that the acceptance test criteria can be met.

After the individual subsystem repair and verification is completed, the build-up of the TMS will be accomplished. The subsystems will be installed and tested. The readiness test will be final acceptance test of the system after final assembly.

TMS REFURBISHMENT TIMELINE



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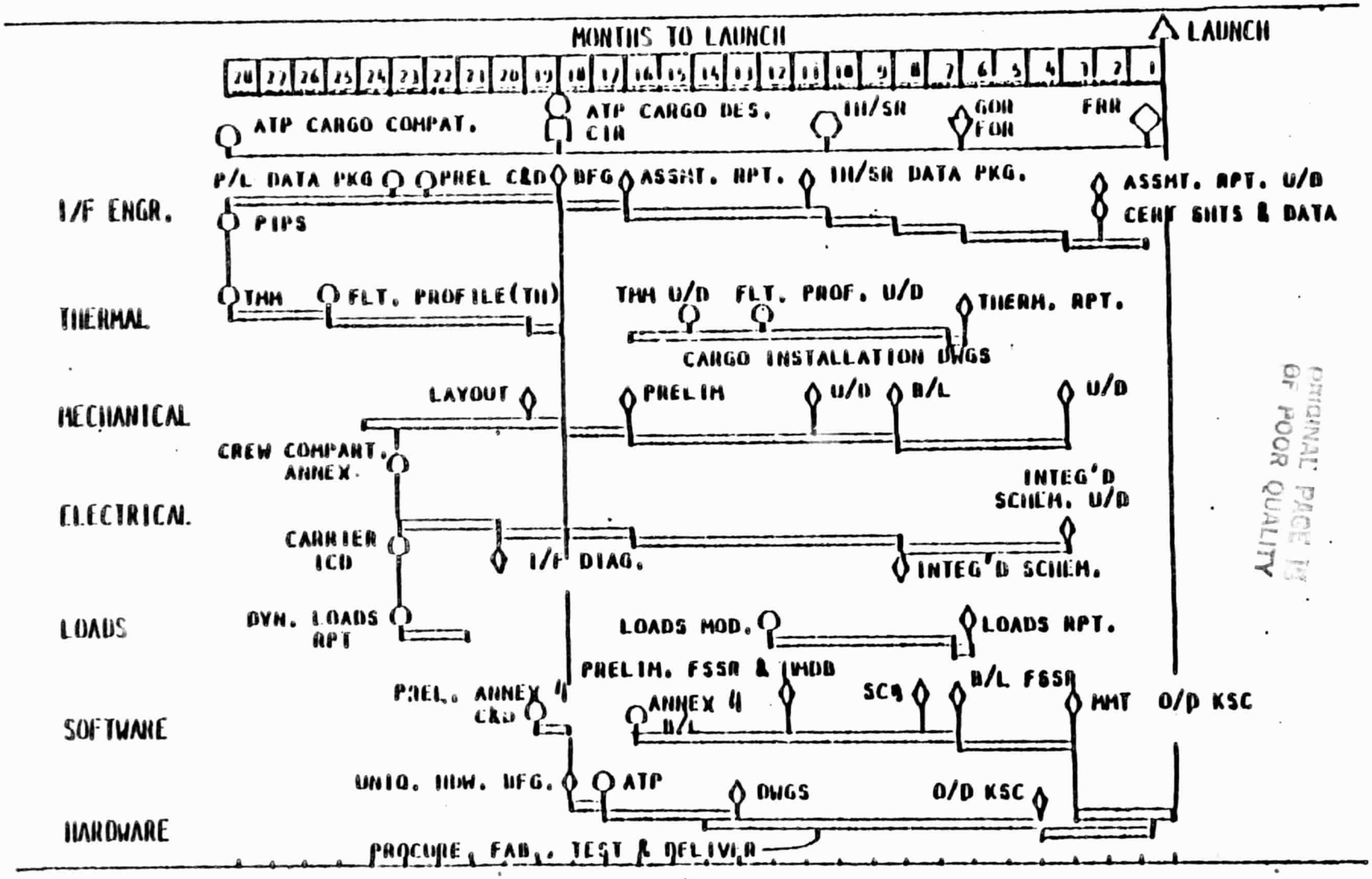
Space Operations and Satellite Systems Division — Rockwell International

37 days
once every 5 years

TMS/CARGO INTEGRATION FLIGHT SCHEDULE

The process of integrating payloads with the Space Transportation System (STS) is shown for a typical schedule of 28 months from requirements development and agreements through flight implementation activities to launch. The schedule depicts the documentation of the Payload Integration Plan (PIP) to provide a single authoritative co-signed (STS/User) document that defines the technical interfaces, engineering analysis, payload requirements and constraints and integration hardware/software, payload safety, and summarizes the optional services. At specified times, the STS will conduct major reviews of the STS plans and preliminary implementation documentation with the user. As part of the integration operation, thermal, mechanical, electrical, and loads analysis will be conducted to assess the compatibility and compliance of the payload with the cargo and STS interfaces. The user is responsible for the assessment and verification that his payload is ready to fly and will certify his payload at the STS conducted Flight Readiness Review (FRR).

TMS/CARGO INTEGRATION FLIGHT SCHEDULE



TMS/CARGO INTEGRATION DOCUMENTS

The facing chart summarizes the documentation required to perform a TMS flight on the STS. Both the number of documents and the number of pages and drawings required for the first TMS flight, as well as subsequent TMS flights are shown.

The recurring costs with each STS launch may be materially reduced by space basing the TMS, and will therefore represent a persistent incentive to evolve to one of the early space basing modes described previously.

SPACE SHUTTLE ORBITER

TMS/CARGO INTEGRATION DOCUMENTS

DOCUMENTS	NON RECURRING			RECURRING		
	NO.	PAGES	DRAWINGS	NO.	PAGES	DRAWINGS
<u>PAYLOAD INTEGRATION</u>						
PAYLOAD INTERFACE	20	763				
PROGRAM MANAGEMENT	19	540				
PAYLOAD DESIGN	19	320	98	2	12	4
<u>CARGO INTEGRATION</u>						
CARGO ASSESSMENT	8	400	16	8	400	16
CARGO MANAGEMENT	14	330		14	150	
<u>STS FLIGHT DESIGN & IMP.</u>						
FLIGHT CERTIFICATION	5	30		5	30	
OPERATION & MAINTENANCE	10	250		10	25	

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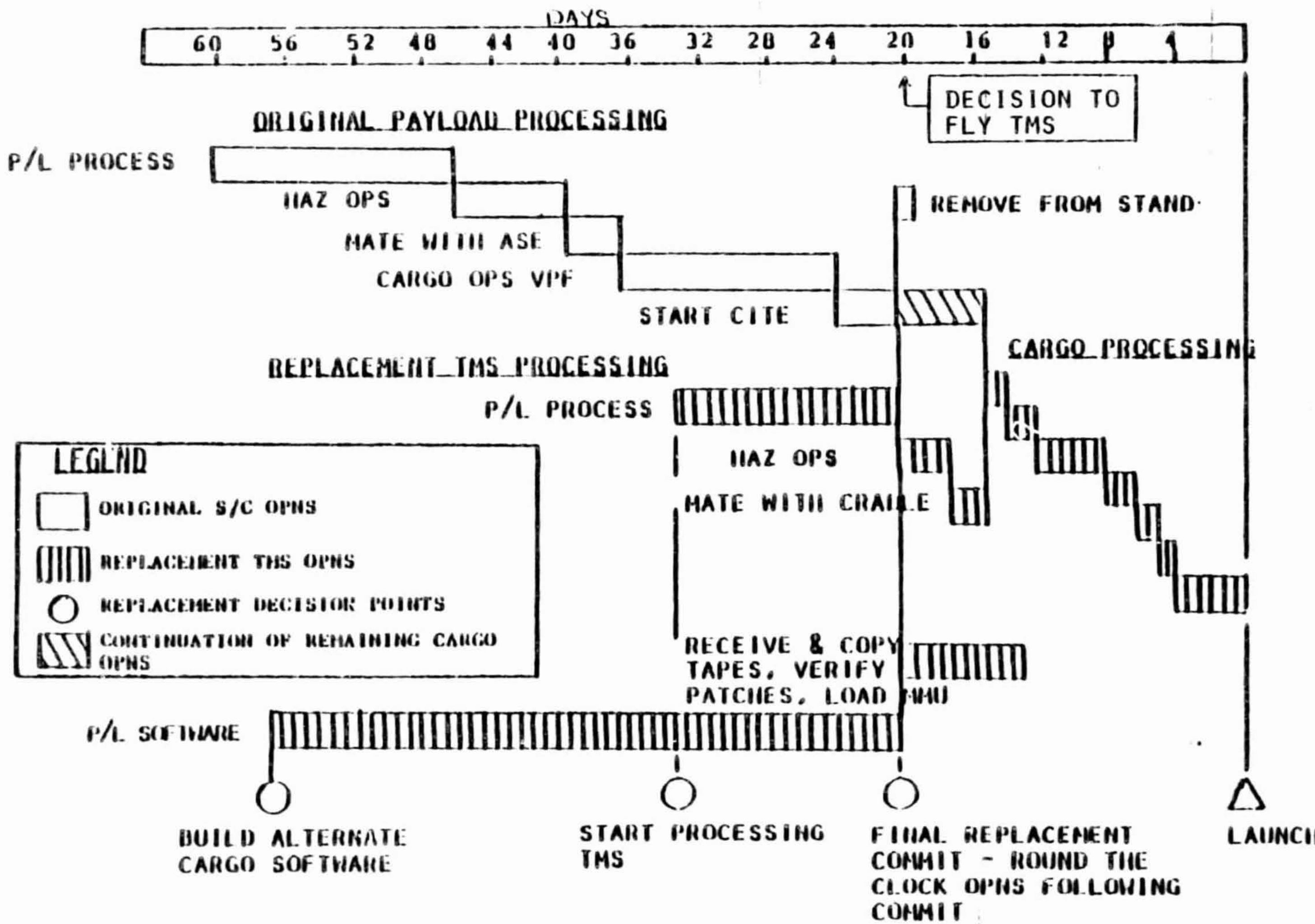
CONTINGENCY MISSION TIMELINE

Replacement of a deployable spacecraft with the TMS spacecraft late in the STS cargo integration cycle requires knowledge that a specific spacecraft may be replaced so that some preparatory work can be completed prior to the final replacement commitment. The chart shows replacement of a typical spacecraft with the TMS. The TMS can be physically interchanged as late as 20 days before launch; however, the mass memory tape MMT for the flight is not applicable to the TMS. The approach to accommodating the TMS software changes is to build an alternate pass tape and subsequently a new MMT. The building of the alternate cargo software is shown as the first decision point no later than 57 days before launch.

The second decision point shown follows the completion of the TMS processing in the payload processing facility (PPF). A determination is made if flight readiness processing of the TMS should be started.

At no later than 20 days prior to launch, a decision must be made to fly the scheduled payload or to replace it with the TMS. Note that the work shift schedule changes from 8 hours per day, 5 days per week, to 12 hours per day, 6 days per week, following the replacement.

CONTINGENCY MISSION TIMELINE



TMS BENEFITS ASSESSMENT STUDY

CONTENTS

- INTRODUCTION
- STUDY OVERVIEW
- TECHNICAL DISCUSSIONS
  - TASK 4.1: MISSION MODELS AND PAYLOAD REQUIREMENTS
  - TASK 4.2: SYSTEMS INTEGRATION REQUIREMENTS
  - TASK 4.3: COSTING ANALYSIS
  - TASK 4.4: TMS BENEFITS ANALYSIS

TECHNICAL DISCUSSION - TASK 4.3 AND 4.4

TMS BENEFITS ANALYSIS

JUSTIFICATION: TELEOPERATOR MANEUVERING SYSTEM NEW START

The objective of the TMS Benefits Study, conducted under contract to MSFC, is to provide a justification for Major System New Start for the Teleoperator Maneuvering System (TMS). To develop justification for a TMS new start, it was necessary to quantitatively examine the benefits derived from each of the TMS functions: satellite servicing, remote inspection, and satellite deployment and retrieval (to and from the nominal STS orbiter parking orbit).

The TMS Benefits Study concluded that cost-avoidance savings could accrue to commercial, scientific, and military space programs by use of TMS for payload deployment and retrieval, and use of its unique function of in-situ satellite servicing. The TMS capability to inspect spaceborne objects, while indisputably valuable from a national security assurance perspective, was not amenable to quantitative evaluation. Although the ground-based TMS showed virtually the same total cost as integral propulsion for single satellite deployment and retrieval across the entire spectrum of payloads included in the Rockwell/TMS mission model, improvements in TMS payload manifesting were investigated under which the TMS yielded advantages vis-a-vis integral propulsion in the deployment and retrieval of satellites.

High priority should be assigned to the TMS New Start in NASA's funding queue, since the investment opportunity is both affordable within existing budget constraints, and commercially attractive, based on its projected high economic rate of return. To delay the TMS New Start would perpetuate the economic loss which arises from the inefficiencies of integral spacecraft propulsion and from premature satellite expenditure on failure, wear-out, depletion of consumables or technological obsolescence.

JUSTIFICATION: TELEOPERATOR MANEUVERING SYSTEM NEW START

SUBSTANTIAL DOLLAR SAVINGS IN MISSION COST

• IMS FUNCTIONS	— SATELLITE DEPLOYMENT & RETRIEVAL. — SERVICING & REFURBISHMENT, INSPECTION
• COST AVOIDANCE POTENTIAL	— SATELLITES EXPENDED ($ LOST) ON FAILURE, ON WEAROUT, ON DEPLETION & ON OBSOLESENCE
• CAPABILITIES NEEDED	— ACCESS TO & RECOVERY OF ON-ORBIT SATELLITES — IN-SITU REPAIR & REFURBISH OF SATELLITES
• IMS BENEFIT	— SERVICING - HUGE POTENTIAL PAYOFF — INSPECTION - MOST EFFECTIVE ALTERNATIVE — DEPLOY, RETRIEVE - AN ADDED SAVING
• IMS PRIORITY	— AN "AFFORDABLE" INVESTMENT OPPORTUNITY — EXCELLENT ECONOMIC RETURN, LOW RISK
• IMPACT OF DELAY	— CONTINUED HIGH COST TO NASA/DoD PROGRAMS — SOME COMMERICAL PROGRAMS NEVER EXPLOITED — COST REMAINS A BARRIER TO UTILIZATION OF THE SPACE FRONTIER

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FUNCTIONS INCLUDED: TMS BENEFITS STUDY

The approach used in the TMS Benefits Study was to evaluate those TMS functions which could be quantitatively assessed and to perform the analysis on the economic measures thereof. The potential economic benefits of both the TMS propulsive function and the TMS servicing function were evaluated. Other functions and capabilities, particularly remote inspection and remote on-orbit fuel transfer, are high-value characteristics but could be only subjectively assessed.

FUNCTIONS INCLUDED: TMS BENEFITS STUDY

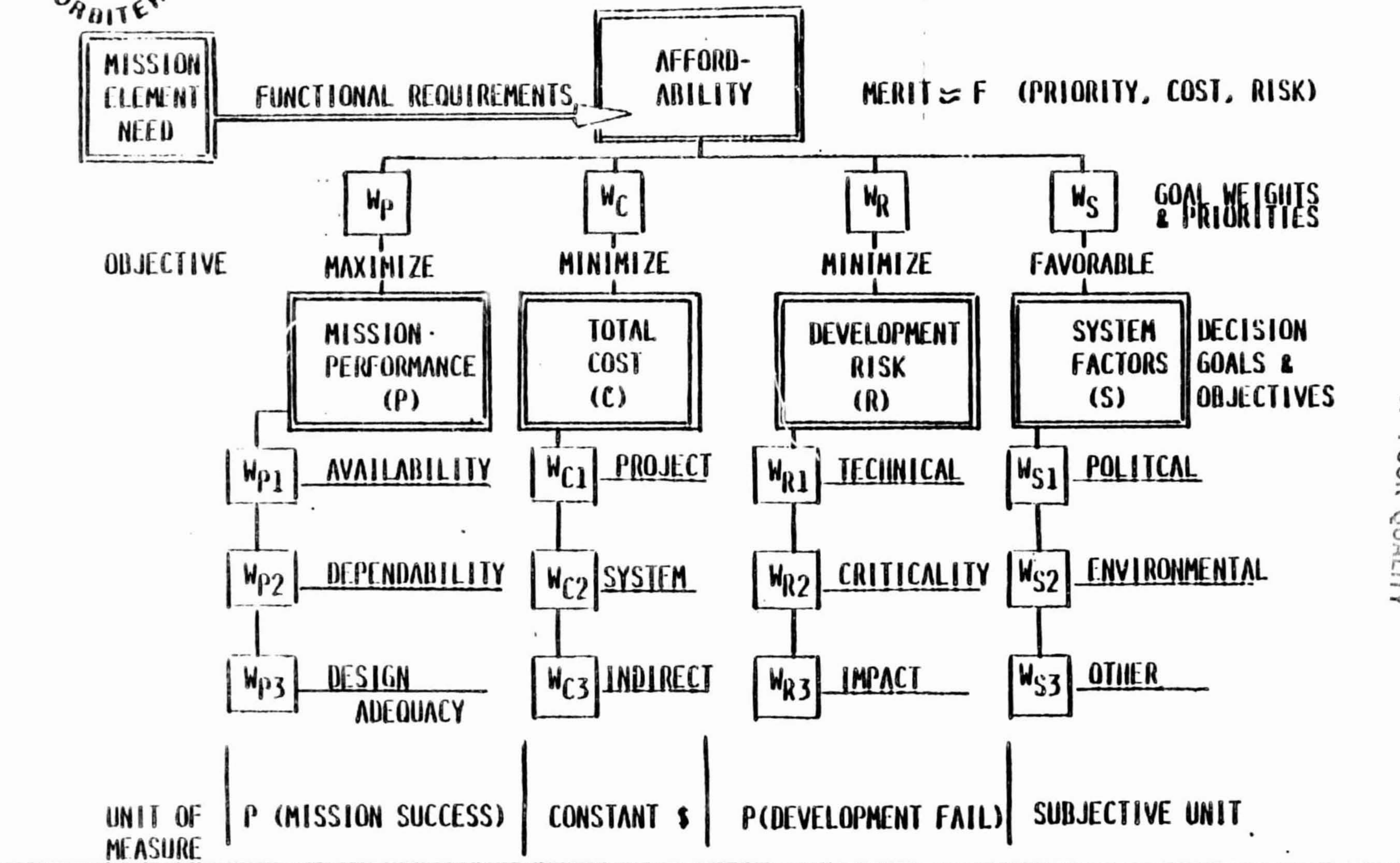
POTENTIAL BENEFIT	QUANTITATIVE OBJECTIVE ASSESSMENT	QUALITATIVE SUBJECTIVE ASSESSMENT		
	MID 1990s POTENTIAL GROSS COST AVOIDANCE	HIGH	MEDIUM	LOW
• SATELLITE SERVICING				
LEO	✓ $\$800\ \bar{M}$ 82 / YEAR			
POLAR	✓ $\$300\ \bar{M}$ 82 / YEAR			
GEO	✓ $\$700\ \bar{M}$ 82 / YEAR			
• SATELLITE DEPLOY/RETRIEVE	DEPENDS ON:			
VS. OMS	- MISSION SHARING			
VS. INTEGRAL PROPULSION	- BASING MODE >> $\$80\bar{M}$ 82/YEAR			
• REMOTE INSPECTION		O		
• DEBRIS REMOVAL, DE-ORBIT			O	
• ORBITAL ASSEMBLY			O	
• HAZARDOUS HANDLING			O	
• REMOTE FUEL TANSFER		O		
• SUBSATELLITE, OV PROXIMITY			O	
• OTHERS				

• COST OF PROVIDING BENEFITS ✓ 12 UNITS; $1+ BILLION '82
✓ TRANSPORTATION COST

"NEED: AFFORDABILITY" METHOD OF EVALUATION

The TMS is an "affordable" concept, justified by the high priority mission need for spacecraft propulsion and on-orbit servicing, its reasonable acquisition cost, and its acceptable programmatic risks.

"NEED: AFFORDABILITY" METHOD OF EVALUATION



FACTORS WHICH DRIVE TMS BENEFITS STUDY

The justification approach used in the TMS Benefits Study was: (1) to identify savings by TMS function, i.e., propulsion and servicing; (2) to estimate the costs incurred by providing TMS functions; and (3) to assess the investment returns of the TMS concept.

FACTORS WHICH DRIVE TMS BENEFITS STUDY

- BENEFITS - PROPULSION
  - NUMBER AND TYPE (DEPLOY, DEPLOY/RETRIEVE) OF MISSIONS REPLACING INTEGRAL PROPULSION AND/OR ORBITER DIRECT INSERTION
  - MULTIPLE MANIFESTING OF DEPLOYMENT MISSIONS; DEPLOY/RETRIEVE MISSION SHARING
  - INTEGRAL PROPULSION OR DIRECT INSERTION COSTS AVOIDED
- BENEFITS - SERVICING
  - EXPECTED LOSS (POTENTIAL SERVICING BENEFIT) PER SATELLITE
  - SERVICEABLE SATELLITE POPULATION PROJECTIONS
  - SERVICING FREQUENCY (SCHEDULED & CONTINGENCY)
- COSTS TO PROVIDE TMS BENEFITS
  - ACQUISITION COST = DDT&E + PRODUCTION
    - FLEET SIZE
    - COST ESTIMATING RELATIONS & METHODS
  - OPERATIONS AND SUPPORT
    - INTEGRATION
    - TMS FLIGHT OPERATIONS
  - STS TRANSPORTATION CHARGES
    - CONFIGURATION (PROPELLANT LOAD & TYPE) SIZING
    - TMS BASING MODE (GROUND OR SPACE) SELECTION
    - STS COST PER FLIGHT AND USER CHARGE (ETR & WTR)

TELEOPERATOR MANEUVERING SYSTEM (TMS) BENEFITS STUDY

The approach used in the Teleoperator Maneuvering System (TMS) Benefits contract has the objective to provide a sufficient justification for Major System New Start (replacement for Mission Element Need Statement) for the TMS. This justification was developed by showing significant benefits (economic returns), affordable development costs, acceptable programmatic risks, and high priority in the NASA program queue.

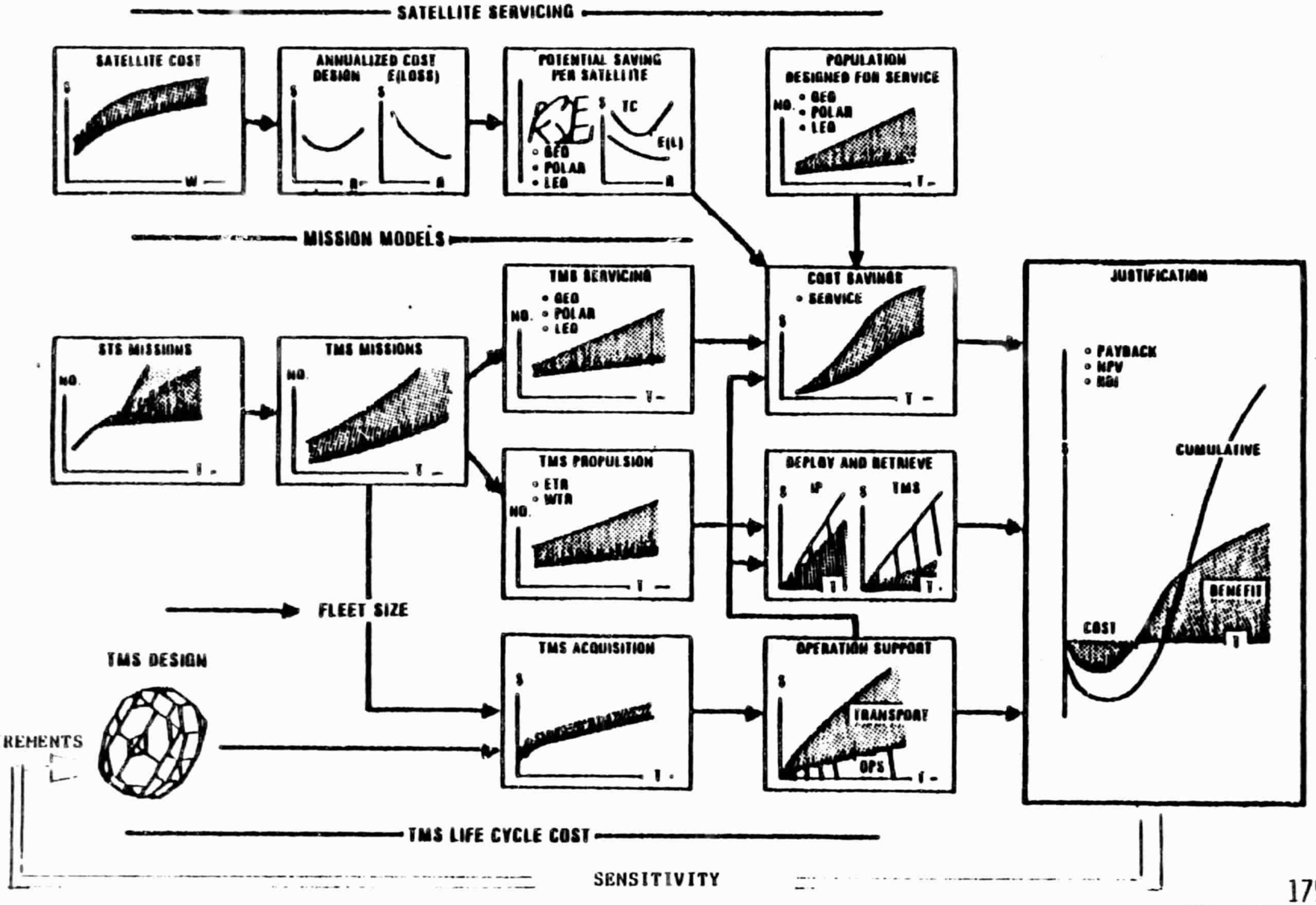
The primary method of defining the need for the Teleoperator Maneuvering System was classical "cost benefit" analysis which led to economic Return on Investment (ROI). Two inputs were required for the ROI analysis, as indicated by two paths leading to (1) cost savings, and (2) TMS Life Cycle Costs (LCC).

Savings accrue to the TMS when used as a deployment/retrieval alternative to integral spacecraft propulsion; however, savings were less than the very favorable satellite servicing benefits. As shown in the upper path, economic savings attributable to the TMS were derived from a comparison of annual costs under present-day operating conditions (which utilize expendable sapcecraft) as opposed to future TMS-enhanced conditions (which may utilize repairable/refurbishable spacecraft).

To determine potential payload savings for the repairable/refurbishable spacecraft mode, annual mission costs were developed for three typical satellite classes, then extrapolated across the TMS mission model which estimates time-phased TMS servicing usage.

The TMS life cycle cost input relies upon parametric Cost Estimating Relationships (CER) for DDT&E and production as a function of TMS fleet size. TMS Operations and Support (O&S) costs were developed for ground-based TMS alternatives. All cost estimates were developed utilizing the technical description provided in the Vought TMS ØA configuration study contract. Satellite costs were estimated from several applicable sources, including the Air Force Unmanned Spacecraft Cost Model, the Rockwell Global Positioning Satellite (GPS) data base and commercial satellite program data.

TELEOPERATOR MANEUVERING SYSTEM (TMS) BENEFITS STUDY



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TMS SHOWS SAVINGS OVER INTEGRAL PROPULSION

Selected improvements in mission planning for the ground based TMS were identified for examination. The most cost effective of these focus on reduction of the recurring STS transport cost. Three promising approaches are: (1) multiple manifesting of deployment payloads and sharing of deployment/retrieval missions, (2) pairing those payloads with the TMS which can more efficiently use its capabilities, and (3) space basing the TMS. The study has revealed TMS savings over integral propulsion by mission sharing, alone. Multiple payload manifesting, optimal payload matching, and space basing will significantly increase savings. The need for further study in these areas is strongly indicated, in view of the definite potential for TMS benefits as a reusable propulsion stage.

Three recent studies have been conducted to determine the cost-effectiveness of the TMS as a propulsive stage versus alternative LEO delivery schemes such as STS orbiter delivery enhancement through addition of OMS kits, direct insertion of the orbiter into a 250 n. mi. + delivery orbit, and/or use of integral spacecraft propulsion. The conclusion reached by these prior studies - - all based on the assumption of a ground-based TMS deploying or retrieving a single satellite per STS trip -- is that the economic trade off between TMS and integral spacecraft propulsion is an economic tossup since the TMS is generally heavier and longer than an optimized integral propulsion system and is, therefore, subjected to higher STS transportation charges. This is mentioned only to emphasize the importance of the kind of mission planning which maximizes shared TMS engagements. Mission sharing is a logical expectation. That there will be incentives encouraging such sharing is also a reasonable assumption. The TMS program should include a planned approach aimed specifically at the promotion, encouragement, and analysis of shared propulsion missions for the TMS.

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- $\boxed{\text{SATELLITE DEPLOYMENT/RETRIEVAL}}$
- SATELLITE SERVICING
- TMS ACQUISITION & OPERATIONS COST
- TMS NET BENEFITS ASSESSMENT

TMS VERSUS INTEGRAL PROPULSION

TMS MULTIPLE ENGAGEMENTS SHOW POTENTIAL BENEFITS

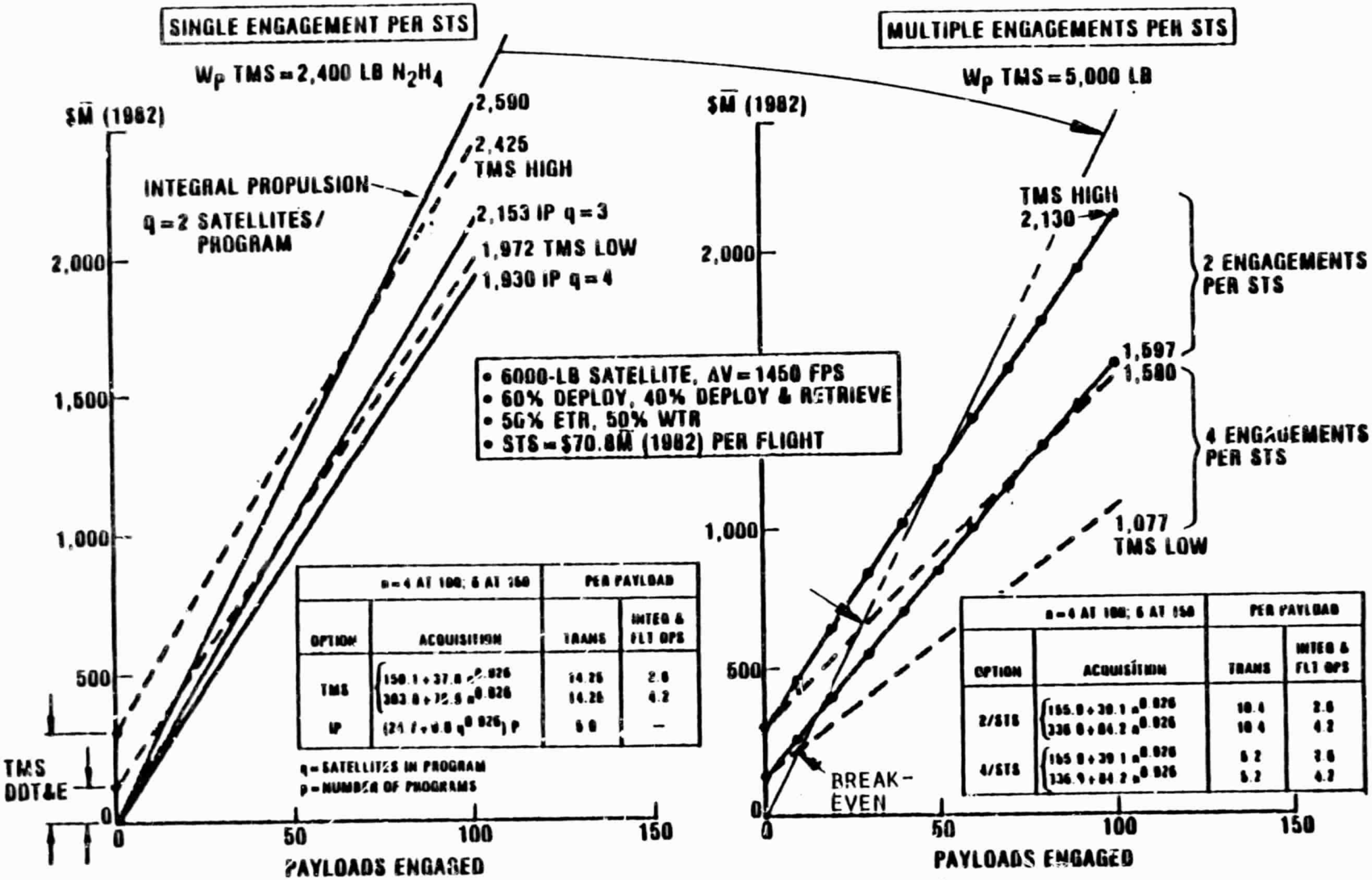
The "even-trade" conclusions reached in studies by three other contractors -- conducted under the constraint of single satellite manifesting per TMS mission -- were validated in parametric analyses of satellite deployment and deploy/retrieve missions from ETR and WTR. However, when multiple engagements per TMS/STS round-trips are considered -- which can be achieved by multiple manifesting of deployments, or mission sharing of deployments and retrievals for a ground-based TMS, or by leaving the TMS on-orbit for multiple uses -- the economic advantage of TMS over integral propulsion improved rapidly.

Data for single engagement missions are given in the left hand figure. The three curves for integral propulsion show costs amortized over 2, 3, and 4 satellites. The two curves for TMS assume Vought costs, and higher costs based on an independent analysis which used the Air Force Space Division Unmanned Spacecraft Cost Model.

However, the right hand figure shows the effect of mission sharing. The solid lines are for 2 engagements/launch, and the dashed lines, 4. An integral propulsion curve has been repeated for ease of comparison, and shows TMS could show a profit after less than 10 engagements. The results represented the turning point in the analysis of TMS as a propulsion stage. For the first time, it was shown that, even with the inclusion of all significant costs, including DDT&E and transportation, TMS provided an economic benefit over integral propulsion.

Since mission sharing is key to TMS propulsion benefits, it is reasonable to inquire as to the expected frequency of such sharing. That there will be cost incentives is obvious. During STS Phase B studies, multiple cargo manifesting played an essential role in the analysis of STS viability. Extending the same benefit to TMS is a reasonable expectation, since it involves no change in manifesting goals. As to the degree of multiple manifesting for TMS, observe the present major emphasis on STS mission sharing. It is suggested that the TMS program office include a planned approach to the promotion and analysis of shared missions for the TMS.

TMS VERSUS INTEGRAL PROPULSION — DEPLOY AND DEPLOY/RETRIEVE



OPTION	ACQUISITION (n = 4 AT 100; 6 AT 150)	PER PAYLOAD: TRANS	PER PAYLOAD: INTEG & FLT OPS
TMS	$150.1 + 37.8\ n^{0.826}$	14.26	2.8
	$303.8 + 75.5\ n^{0.826}$	14.26	4.2
IP	$(24.7 + 6.8\ q^{0.826})\ p$	6.0	—

OPTION	ACQUISITION (n = 4 AT 100; 6 AT 150)	PER PAYLOAD: TRANS	PER PAYLOAD: INTEG & FLT OPS
2/STS	$155.0 + 39.1\ n^{0.826}$	10.4	2.8
	$336.0 + 84.2\ n^{0.826}$	10.4	4.2
4/STS	$155.0 + 39.1\ n^{0.826}$	5.2	2.8
	$336.9 + 84.2\ n^{0.826}$	5.2	4.2

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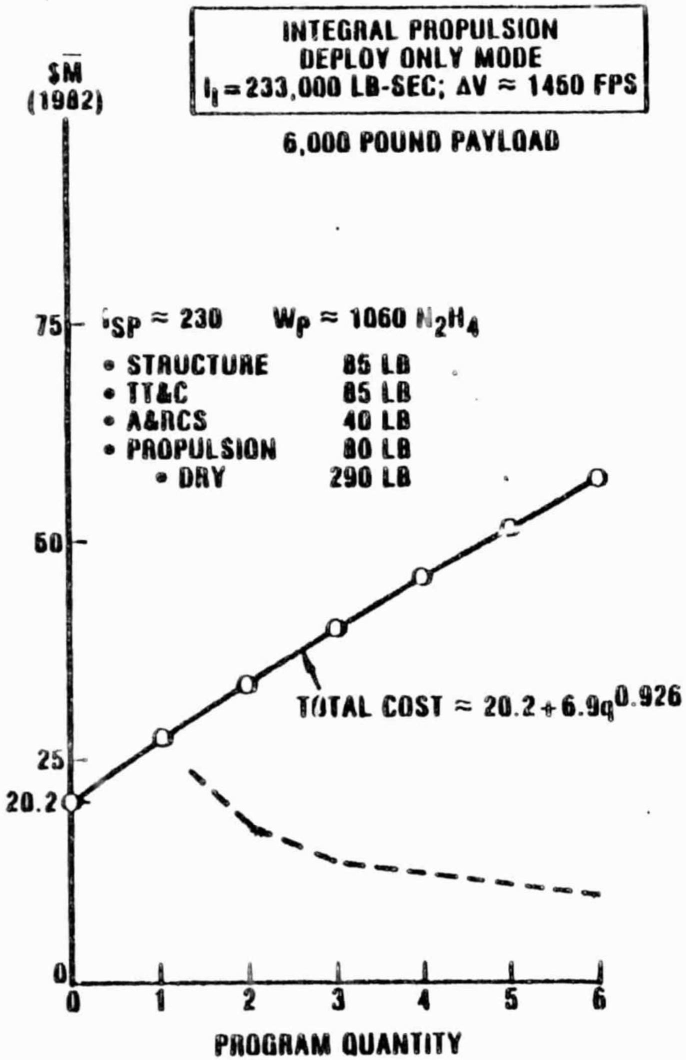
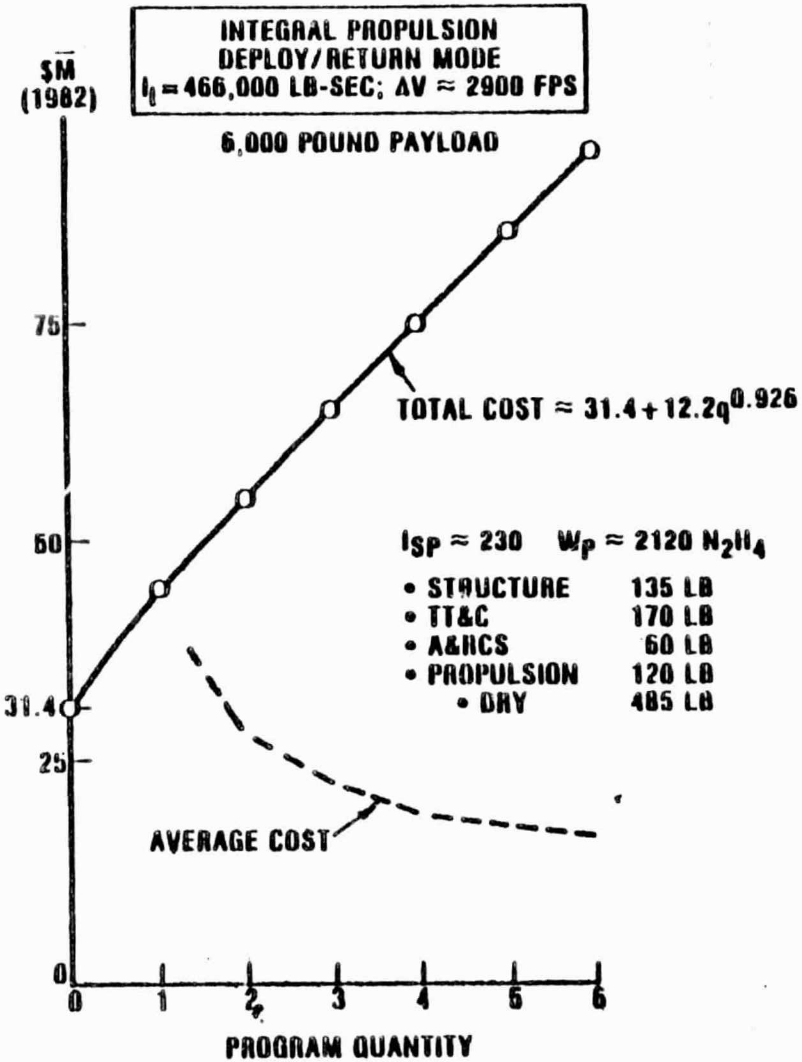
INTEGRAL PROPULSION DEVELOPMENT AND PRODUCTION COSTS

The total cost of using integral spacecraft propulsion for satellite deployment and retrieval is extremely sensitive to the number of satellites across which the program non-recurring acquisition cost is amortized. Acquisition cost estimates for the typical deployment mission integral propulsion system range from \$9.4 $\overline{M}_{82}$ (6 satellites per program) to as much as \$27.1 $\overline{M}_{82}$ (1 satellite per program); and from \$15.9 $\overline{M}_{82}$ to \$43.6 $\overline{M}_{82}$ for the deploy + retrieve mission. Weight-based STS transportation charge factors for integral propulsion at ETR range from 0.0277 to 0.0534 + ASE Δmass differential for the deploy-only and deploy + retrieve missions respectively; from 0.0542 to 0.1085 respectively at WTR.

Typical 6,000 lb satellite weight has been estimated from mid-1980's STS manifested payload characteristics with allowance for weight growth and length reduction (constant volume as payload diameters utilize the full 15' diameter of the orbiter payload bay).

INTEGRAL PROPULSION DEVELOPMENT AND PRODUCTION COSTS





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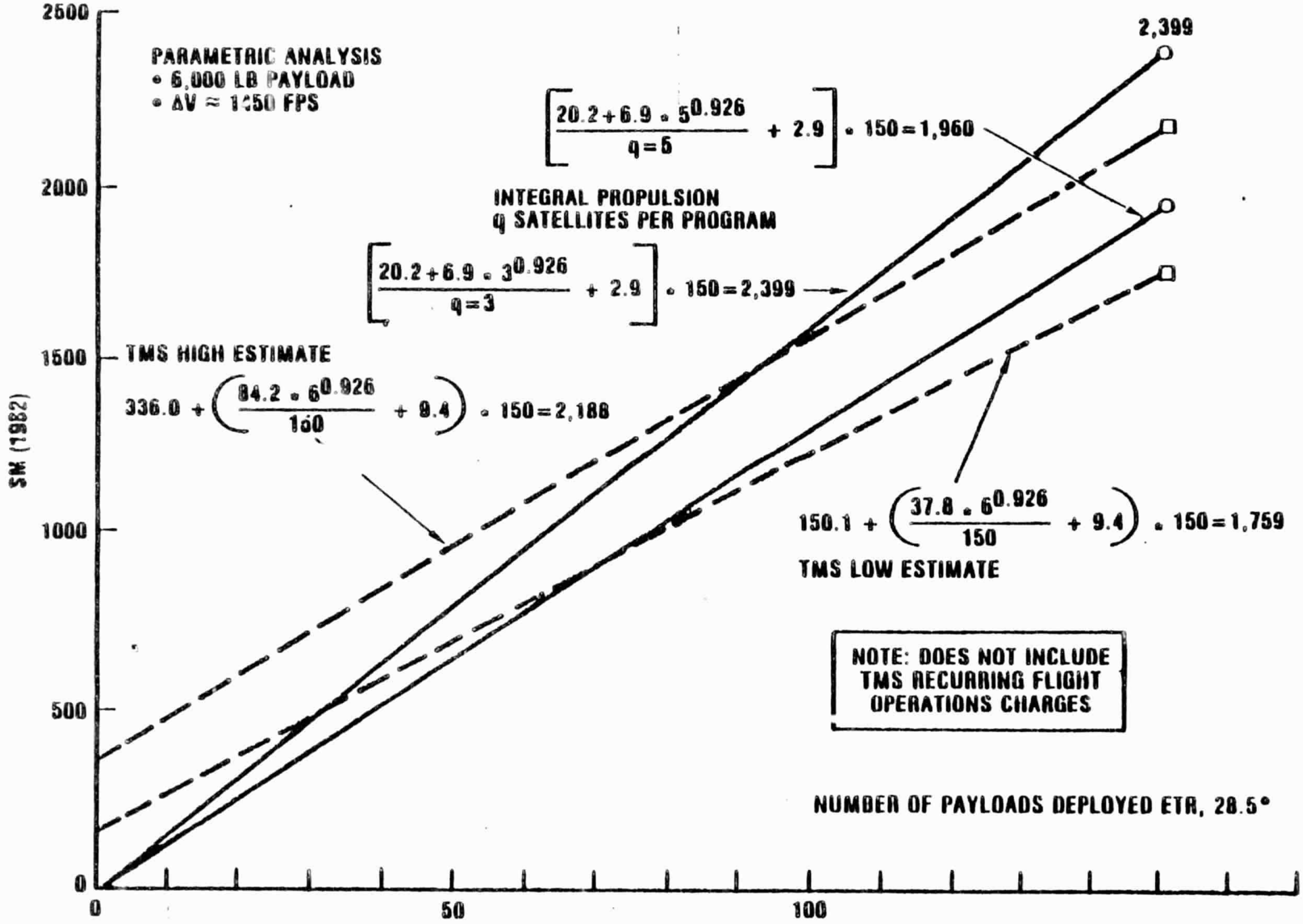
ETR, DEPLOYMENT ONLY MODE, 28.5° ORBIT

Under the baseline assumption set of (1) a ground based TMS, and (2) single deployment per STS round-trip, the total cost of deploying 100-150 payloads from 28.5° ETR to approximately 600 nautical miles is essentially the same using either TMS or integral spacecraft propulsion.

TMS acquisition costs have been estimated as a range based on a useful life of 25 missions per TMS unit; TMS transportation costs have been estimated at \$8.5 $\bar{M}_{82}$ per mission (5,851 lbs launch mass including propellant; \$70.8 $\bar{M}_{82}$ STS launch cost); TMS/STS integration costs have been estimated at \$1.0 $\bar{M}_{82}$ per mission; but TMS flight operations costs (at least \$2.5 $\bar{M}$ per mission) are excluded.

Integral propulsion acquisition costs have been estimated as a range based on the number of satellites per program; integral propulsion (length driven) transportation costs have been estimated at \$2.9 $\bar{M}_{82}$ per mission (1,300 lbs launch mass including propellant; length increment to payload = 18"; \$70.8 $\bar{M}_{82}$ STS launch cost); flight operations costs are not applicable to integral propulsion.

ETR DEPLOYMENT ONLY MODE, 28.5° ORBIT



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TMS VS. INTEGRAL PROPULSION SATELLITE DEPLOYMENT MISSION

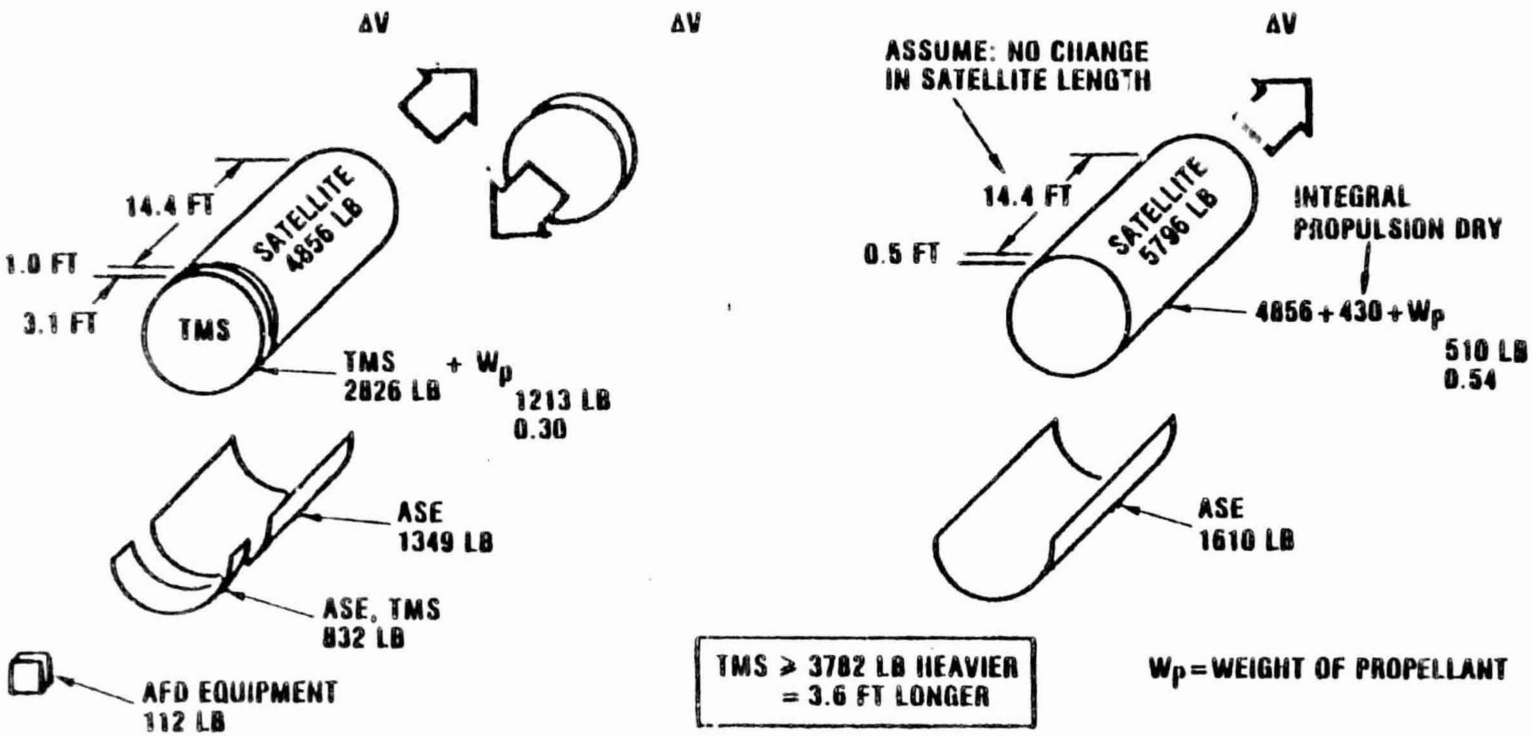
The TMS alternative for satellite deployment and retrieval is characterized by a significantly lower acquisition cost per payload engagement than the integral propulsion option; however, the TMS is both heavier and longer than an optimized integral propulsion system, leading to higher recurring STS transport charges. For the typical single payload deployment function, the TMS is at least 3782 lbs. heavier and 3.6 feet longer than an optimized integral propulsion unit; for payload retrieval, the TMS is at a greater disadvantage since the TMS, its cradle and its orbiter aft flight deck equipment, along with sufficient propellant for the two-way out-retrieve function must be transported in the orbiter payload bay.

However, multiple manifesting of deployed payloads and sharing of deploy/retrieve missions reverses these relationships by allowing TMS weight or length to be amortized over multiple payloads or propulsion engagements.

TMS VERSUS INTEGRAL PROPULSION SATELLITE DEPLOYMENT MISSION (20 SATELLITE SAMPLE: 14 ETR, 6 WTR)

NOTE: W_p BASED ON SPECIFIC MISSION REQUIREMENT

LAUNCH MASS (LB) TMS 11,188 LB	LAUNCH MASS (LB) IP 7,406 LB
DUAL ELV/STS DESIGN LENGTH ≈ 18.5 FT	DUAL ELV/STS DESIGN LENGTH ≈ 14.9 FT



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STS TRANSPORT COST PENALTY, Δ LAUNCH MASS, Δ LAUNCH LENGTH

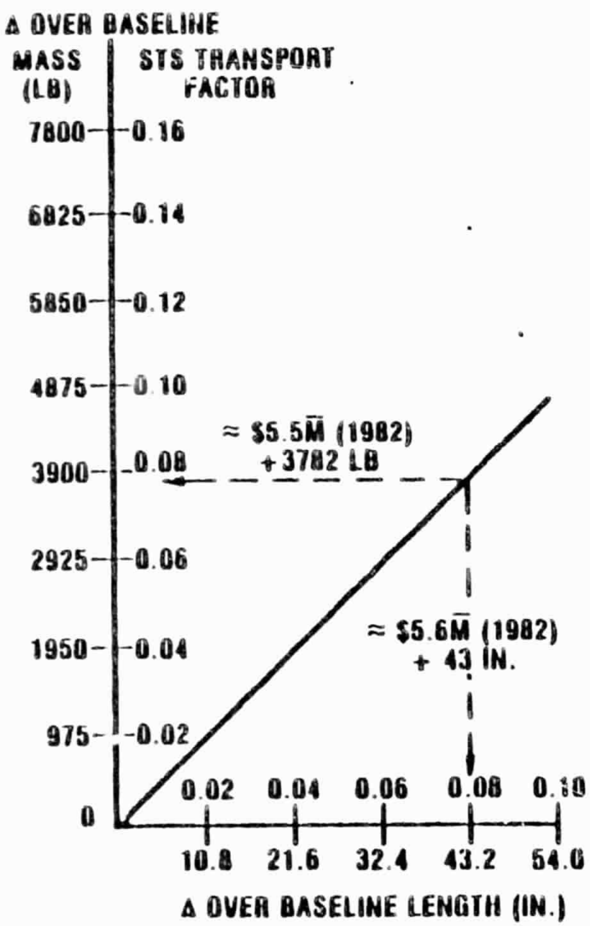
At ETR 28.5°, the added weight ($\geqslant$ 3782 lbs) and added length ($\approx$43 inches) of the TMS for the typical deployment function translate into approximately equal recurring transport penalties ($\approx$ \$5.5 M82 per payload) compared to the integral propulsion alternative, using the STS user charge applicable through FY 1988 for charging purposes and assuming both single payload manifesting and zero length added by integral propulsion. As payload delivery capacity of the STS diminishes with increasing orbital inclination, the TMS weight penalty ($\geqslant$ 3782 lbs) converts to higher recurring transport cost penalties which dominate the added length.

As noted in prior charts, multiple manifesting reverses these relationships; integral propulsion definitely adds length to any payload of given diameter.

STS TRANSPORT COST PENALTY Δ LAUNCH MASS, Δ LAUNCH LENGTH (BASED ON USER CHARGE THROUGH FY 1988)

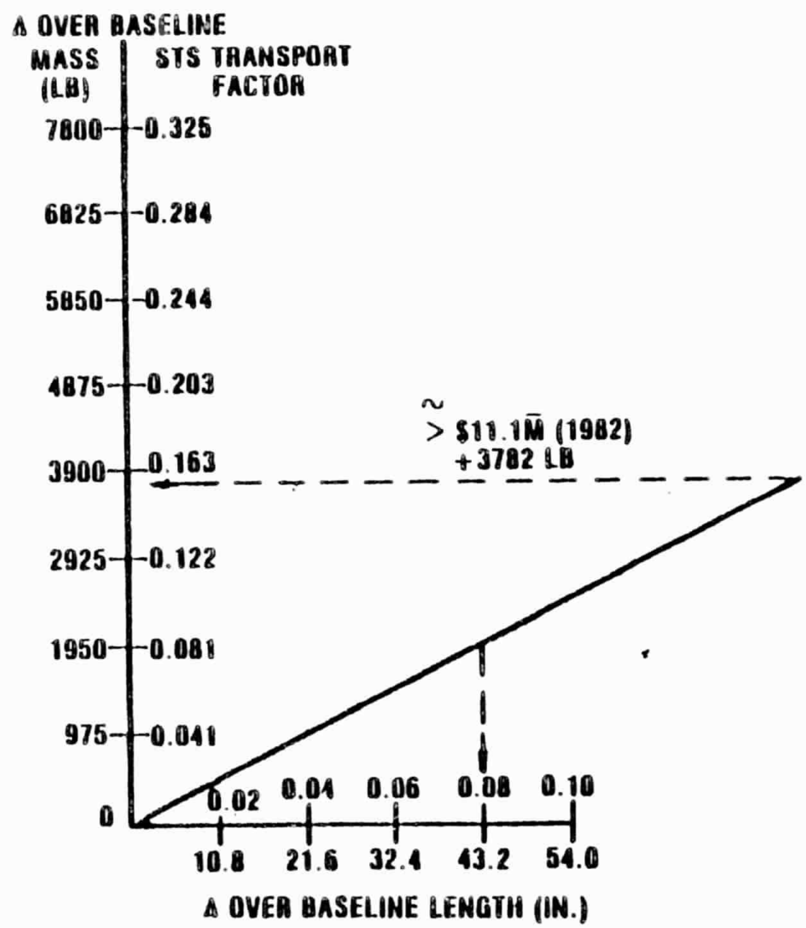
ETR LAUNCH, 28.5°
PENALTY PER PAYLOAD

• USER CHARGE ≈ $70.8M (1982) PER FLIGHT



WTR LAUNCH, 98°
PENALTY PER PAYLOAD

• USER CHARGE ≈ $70.8M (1982) PER FLIGHT



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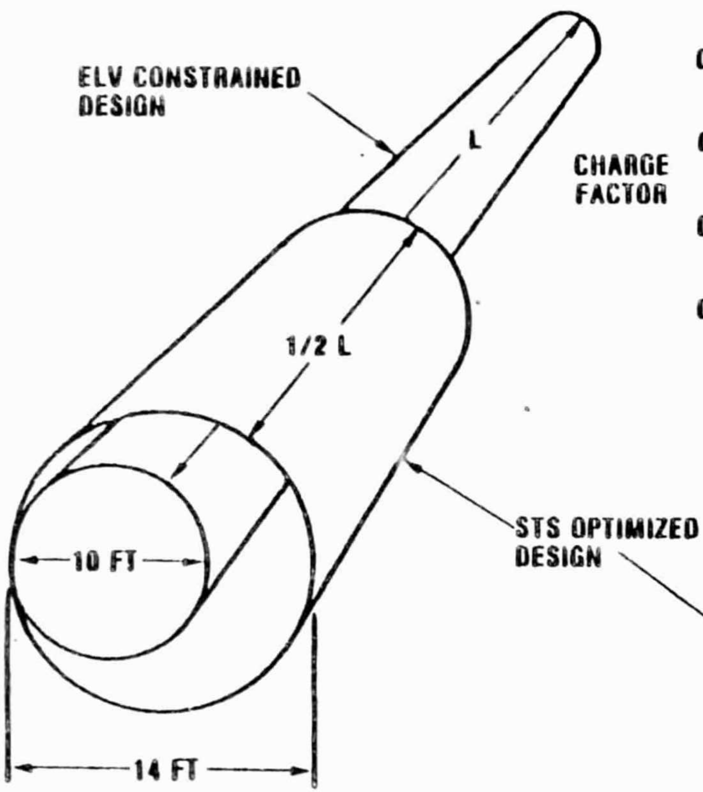
CHARACTERISTICS OF STS SHUTTLE OPTIMIZED CARGO

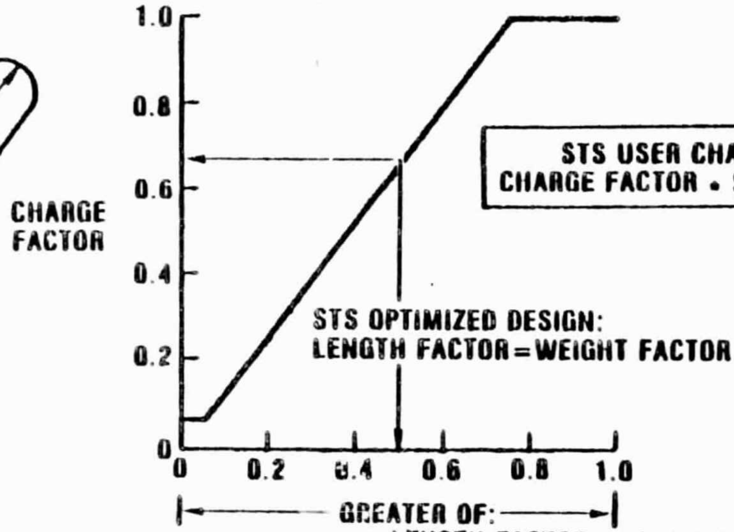
Some prior studies have based the STS transportation charge differential between TMS and integral propulsion on the differential length added to the satellite by each option. The rationale underlying the use of length-based STS change factors, rather than weight-based, is derived from the current volume characteristics of dual-compatible satellite designs which are diameter constrained by ELV capacity.

:ure satellite designs, however, are likely to tend toward taking advantage of the increased diameter of the STS orbiter payload bay and optimize the payload length and weight characteristics (in the absence of other technical design constraints which force configuration) such that any added length or any added weight results in added STS transportation cost. While increments to STS transportation changes are equally sensitive to equal incremental length or weight changes at 28.5° ETR, these recurring costs are much more sensitive to weight changes than to length changes at any higher inclination due to the decreased weight delivery capacity of the STS.

CHARACTERISTICS OF STS SHUTTLE OPTIMIZED CARGO

- SHORTER THAN ELV PAYLOADS
- HEAVIER PER LINEAL FOOT





STS USER CHARGE = CHARGE FACTOR • $38M (1975)

LENGTH FACTOR = L/45 FT
WEIGHT FACTOR = W/48,750 LB ETR 28.5°
= W/24,000 LB WTR 104.0°

I°	WEIGHT UP (LB)	LENGTH UP (FT)	VOLUME UP (FT^3)	OPTIMAL CARGO UNIT (LB/FT^3)
28.5	65,000	60	9,236†	7.0
56.0	60,000	60	9,236	6.5
60.0	57,000	60	9,236	6.2
90.0	38,000	60	9,236	4.1
104.0	32,000	60	9,236	3.5

†ASSUMES 14 FT USABLE OUTSIDE DIAMETER CARGO UNIT

92SSV126168

TMS BENEFITS SENSITIVITY TO CHANGES IN LAUNCH CHARGES

ETR COST PER FLIGHT, AND PRICING POLICY

The recurring STS transportation cost penalty incurred by the heavier, longer TMS is also extremely sensitive to potential changes in the STS user charge. Current NASA STS pricing policy subsidizes the payload user community by charging less for each Space Shuttle flight than its cost, and this policy is expected to continue through at least the end of FY 1988.

ETR launch cost per STS flight has been projected to decline rapidly toward $92M_{82}$ ($\approx$ $50M_{75}$) average in the early 1990's given a combined ETR and WTR STS flight rate of 24 launches per year. WTR launch costs at the same combined flight rate have been projected at about 1/3 higher than ETR, or $\approx$ $122M_{82}$ per flight.

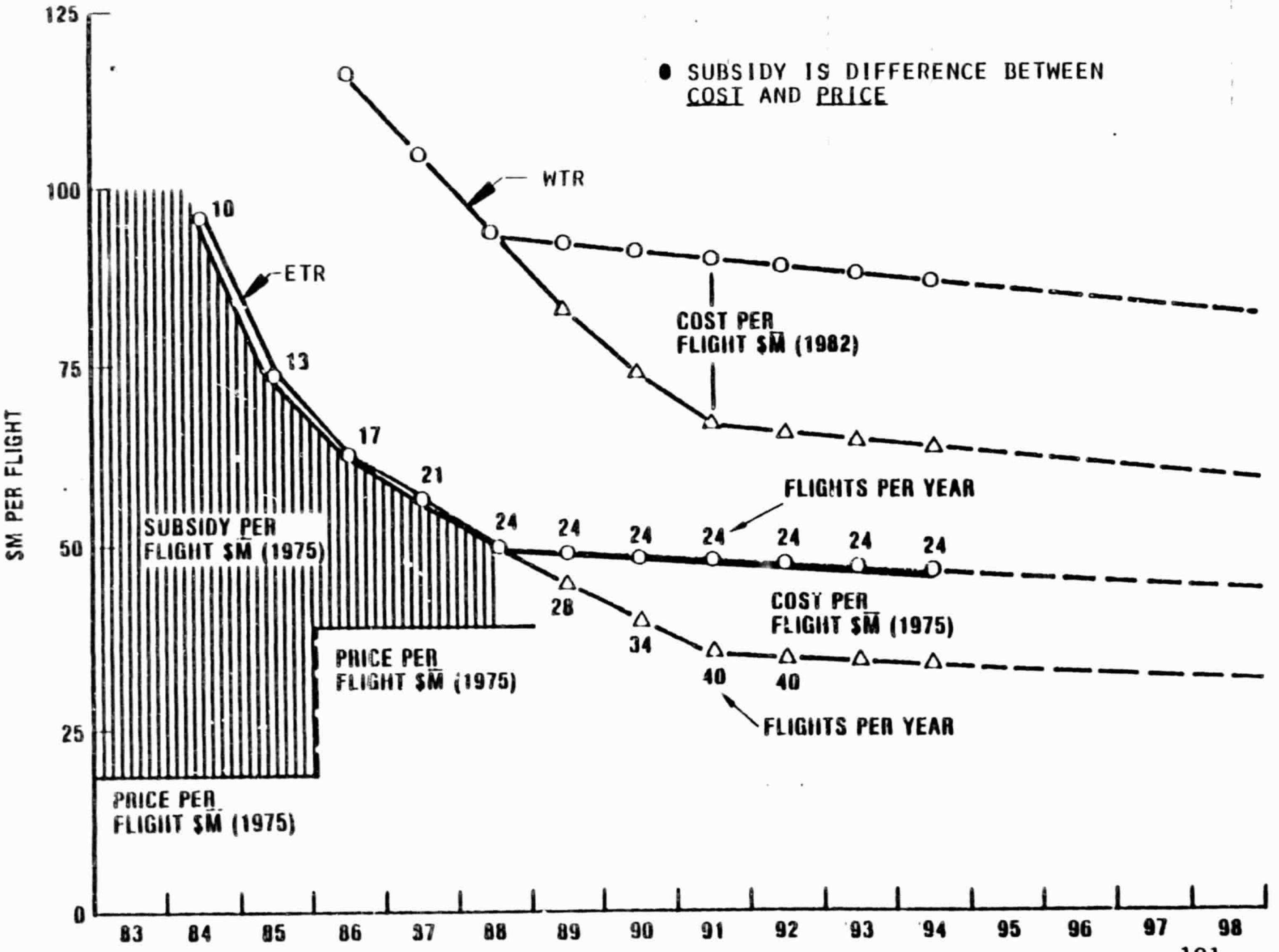
- TMS Servicing Benefits Increase With Launch Charges:

  The TMS, with servicer and modules, is 5 feet shorter than the ASE required for Orbiter/EVA servicing. TMS cargo weight is 5700 pounds lighter.

- TMS Propulsion Benefits Decrease With Higher Launch Charge:

  TMS is typically 2.8 feet longer and 3800 pounds heavier than integral propulsion. Assumes average length penalty for fully buried integral propulsion of 0.75 foot.

ETR COST PER FLIGHT AND PRICING POLICY



92SSV126166

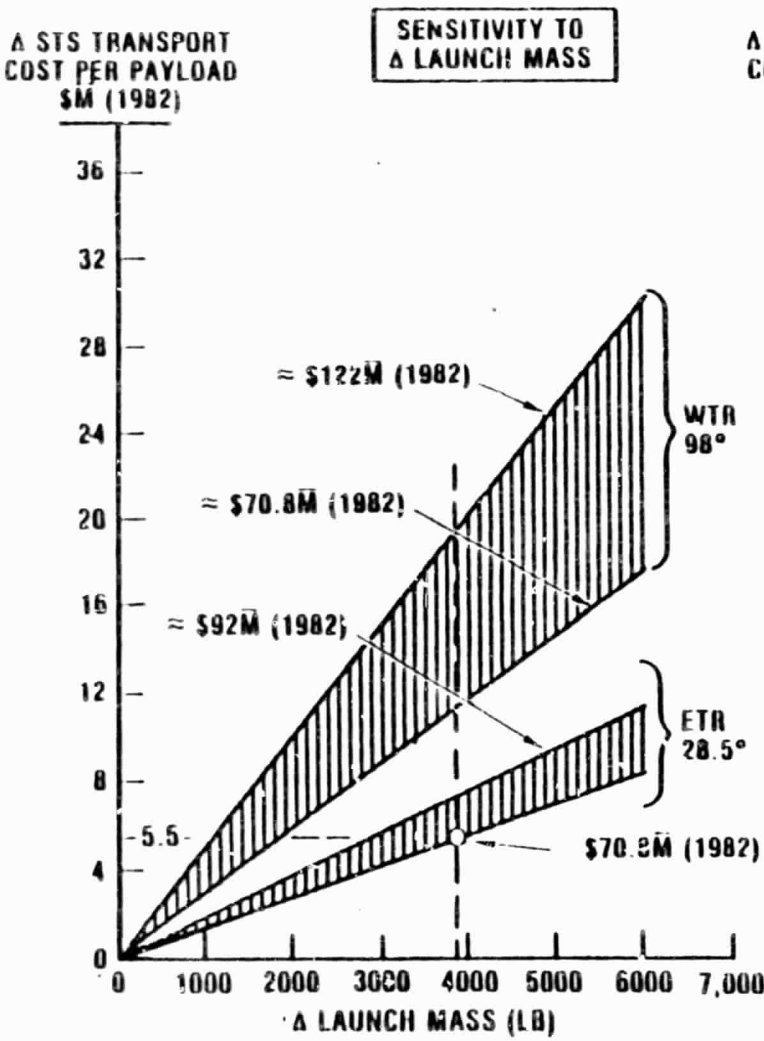
TRANSPORT COST IS EXTREMELY SENSITIVE TO Δ MASS

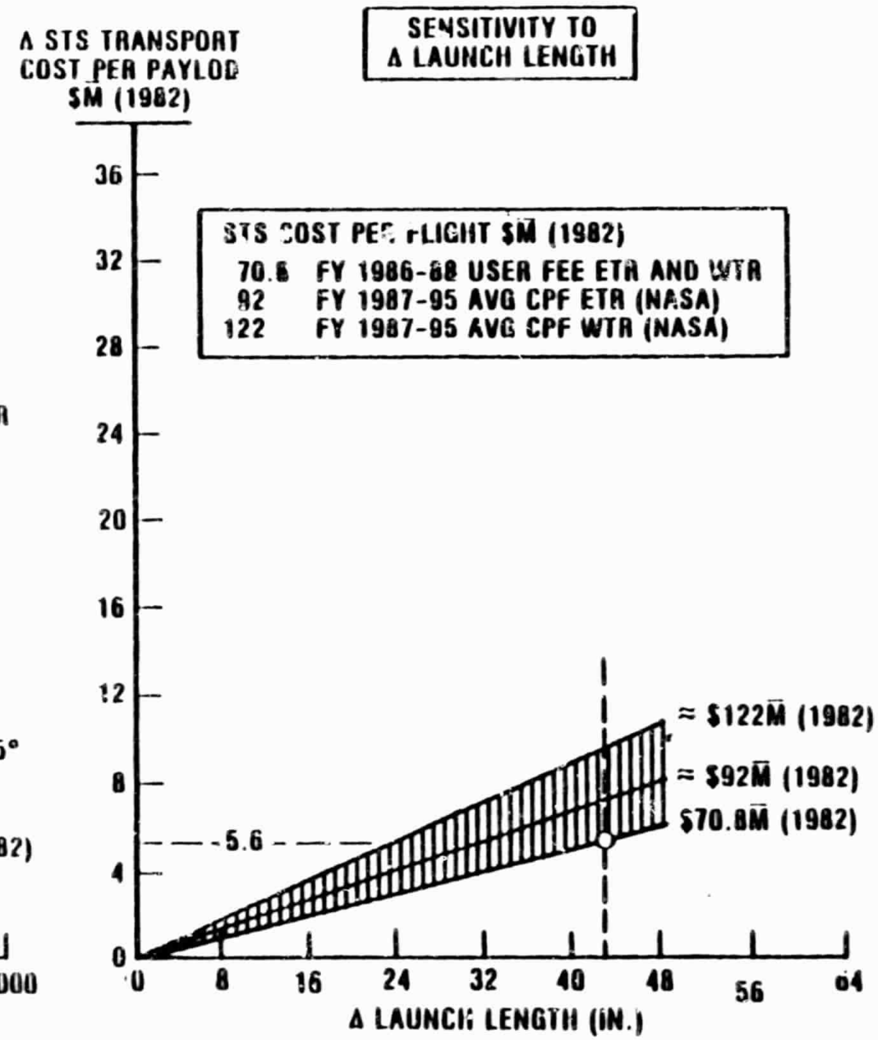
The extreme sensitivity of differential transport cost per payload -- again assuming single manifesting of a ground-based TMS -- with respect to differential launch mass and/or differential launch length is shown for ETR & WTR for various NASA user charge structures.

The 3782 pound added TMS launch weight compared to integral propulsion which has been translated into an approximate \$5.5 $\overline{M}_{82}$ recurring cost per payload penalty in the foregoing parametric analyses, could realistically be as high as \$20 $\overline{M}_{82}$ per payload.

This strongly suggests that, for the TMS to be cost-effective vis-a-vis integral spacecraft propulsion, the recurring transportation cost penalty incurred by the heavier, longer TMS must either be minimized by spreading the transportation cost across several multiple-manifested payloads or be nearly eliminated by leaving the TMS on-orbit for multiple uses per STS round-trip.

TRANSPORT COST IS EXTREMELY SENSITIVE TO Δ MASS





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92SSV126167

ON-ORBIT REFUELING OF TMS, ETR DE ‹OYMENT 28.5°

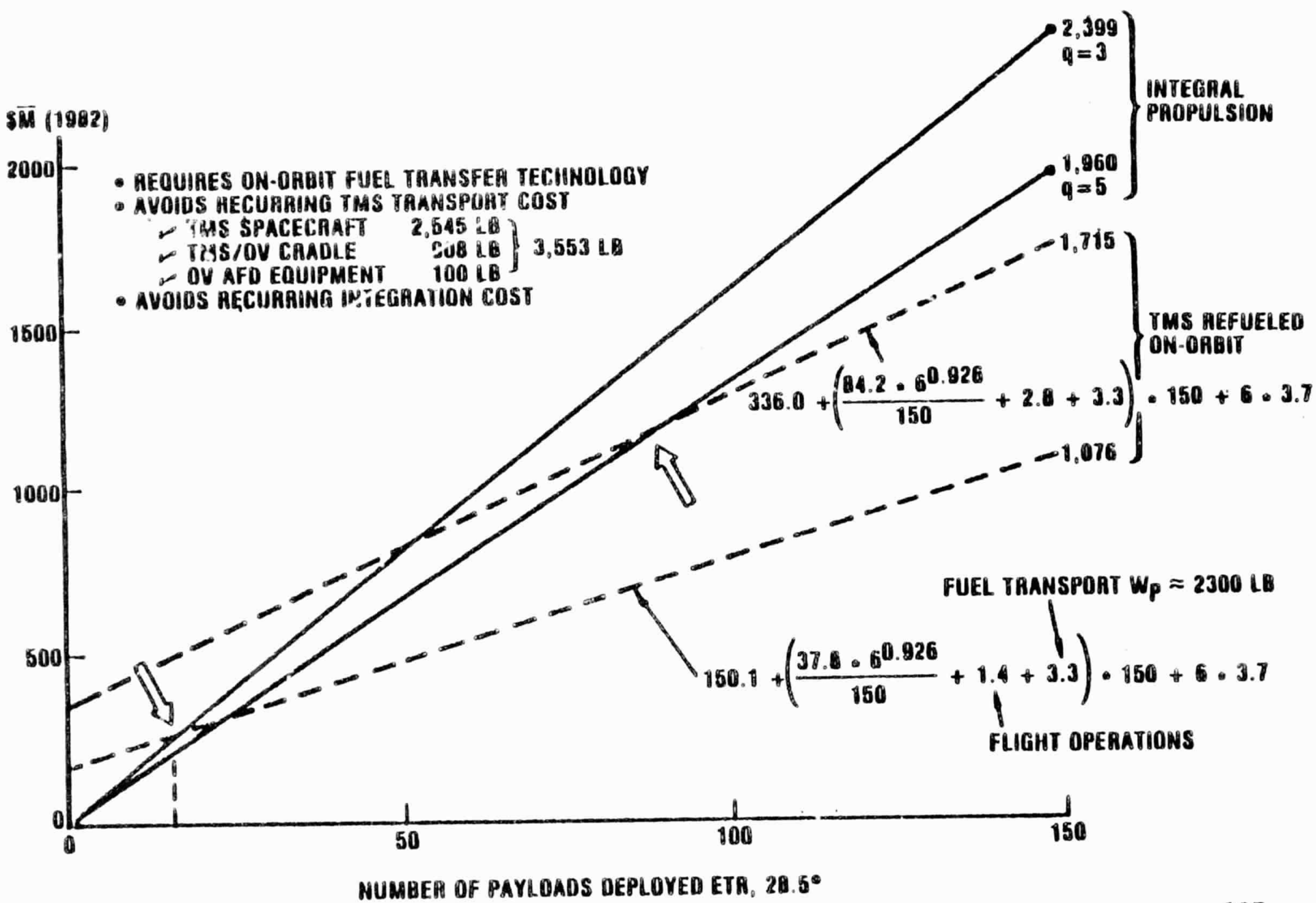
One highly effective operational mode improvement for TMS utilization would be to leave the TMS on-orbit near the main STS delivery path for multiple deployments and/or retrievals, and to refuel the TMS as necessary from the STS orbiter. This scheme would require development of on-orbit fuel transfer technology (already at an advanced stage and potentially sufficient for demonstration in the near-term), but would avoid both the recurring TMS transportation cost and the recurring TMS integration charge.

Adoption of this operating mode for ETR 28.5° deployment missions offers the potential to reduce payload deployment costs by 50% or more compared to the use of integral spacecraft propulsion.

A symbiotic cost adv... e of on-orbit refueling technology envisions payloads launched dry (with signif... t weight savings to the payload), checked out and fueled prior to deployment, then deployed by a space-based TMS.

TMS SAVINGS OF 50% OVER INTEGRAL PROPULSION BY ON ORBIT REFUELING FROM ORBITER OMS POD TANKS

ON-ORBIT REFUELING OF TMS, ETR DEPLOYMENT 28.5°



92SSV126178

SATELLITE SERVICING

Satellite remote servicing -- a unique functional capability provided by the TMS -- generates an extremely high pay-off by significantly reducing the mission cost to the payload user community.

- SATELLITE DEPLOYMENT/RETRIEVAL
  - $\boxed{\text{• SATELLITE SERVICING}}$
    - TMS ACQUISITION & OPERATIONS COST
      - TMS NET BENEFITS ASSESSMENT

MAIN IDEAS - TMS GENERATES HIGH PAYOFF

Preliminary analysis conducted by Rockwell under IR&D during the early part of FY 1982 indicates that the TMS significantly enhances STS and orbiter by providing the capability to service payloads on-orbit and/or return a payload to the orbiter where it may be serviced and subsequently redeployed or, at worst, returned to the earth for refurbishment or salvage. This is extremely valuable, since the payload commonly accounts for more than three-fourths of the users total mission cost. The TMS is expected to generate significant benefits by extending the useful life of an existing payload, rather than expending the payload when failure or depletion of its consumables occurs.

For contractual purposes, a ground-based TMS was analyzed; space-basing of the TMS was concurrently investigated under supporting Rockwell IR&D. In evaluating the TMS servicing-related gross benefits, the basing mode was unimportant, thus only the orbital capability to perform the servicing mission was considered. Selection of basing mode (ground or space) drives the costs of operating and maintaining the TMS, and will be discussed in the life cycle cost section.

MAIN IDEAS - TMS GENERATES HIGH PAYOFF

- <u>TOTAL MISSION COST</u> TO PAYLOAD USER IS KEY

  <u>PAYLOAD COST</u> DRIVES TOTAL MISSION COST

  <u>PAYLOAD INSURANCE</u> IS EXPENSIVE

  - LAUNCH RISK
  - OPERATION RISK
  - EXPENDED AT END – OPERATIONAL LIFE

- TELEOPERATOR PROVIDES <u>ORBITAL ACCESS TO PAYLOADS</u>

  SERVICE & REFURBISH VS. EXPEND

  REPAIR, RECOVER VS. "LOSS" ON FAILURE

- <u>SECTION EVALUATES CAPABILITY, NOT BASING MODE</u>

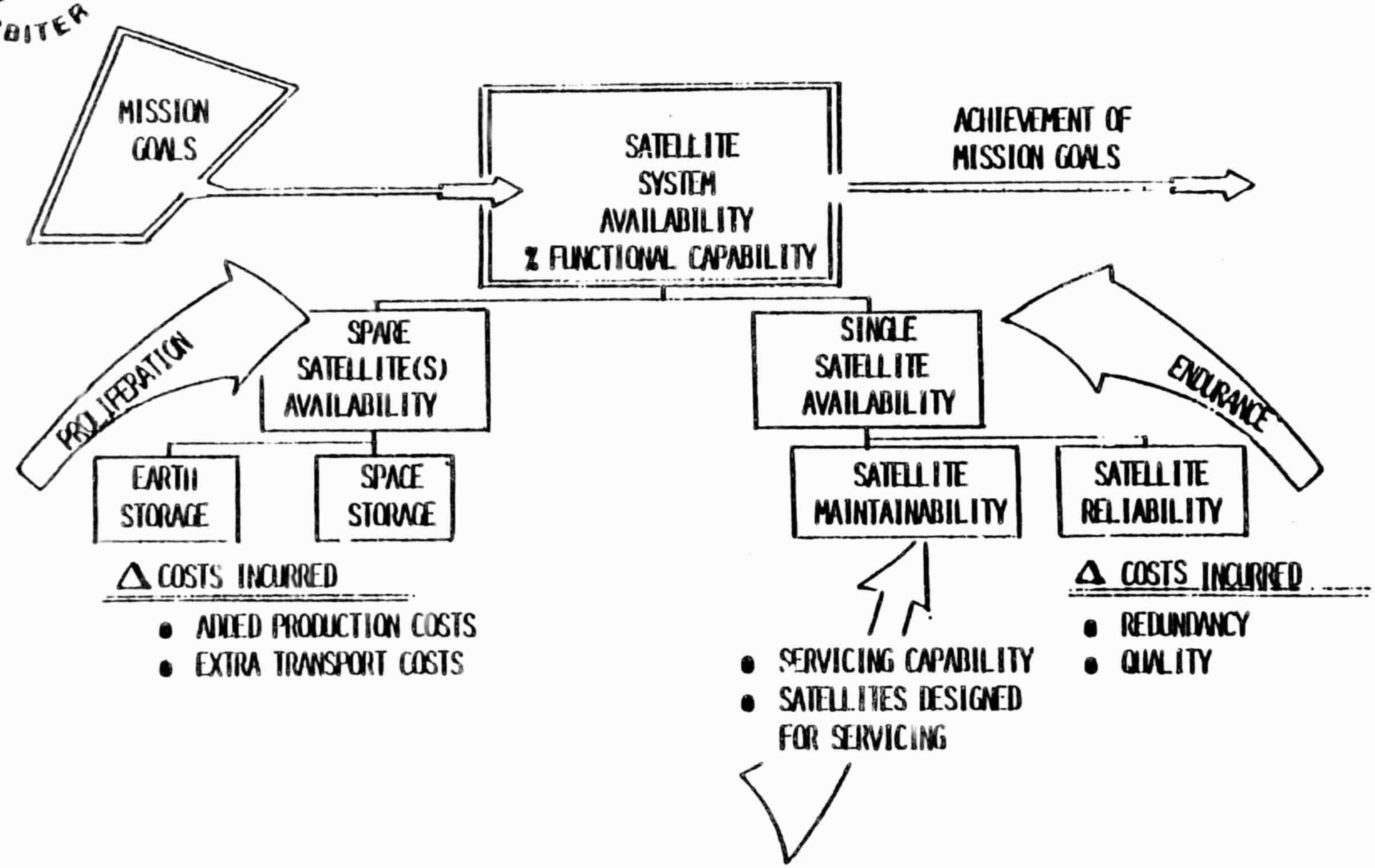
  <u>TRANSPORTATION & INTEGRATION COSTS IGNORED</u>

  CAPABILITY ASSUMED RESIDENT FOR RESPONSE

SYSTEM AVAILABILITY YIELDS MISSION ACCOMPLISHMENT

Satellite maintenance is a more cost-effective method of ensuring a given level of satellite system availability than either of today's current practices -- designed in reliability, and proliferation through sparing.

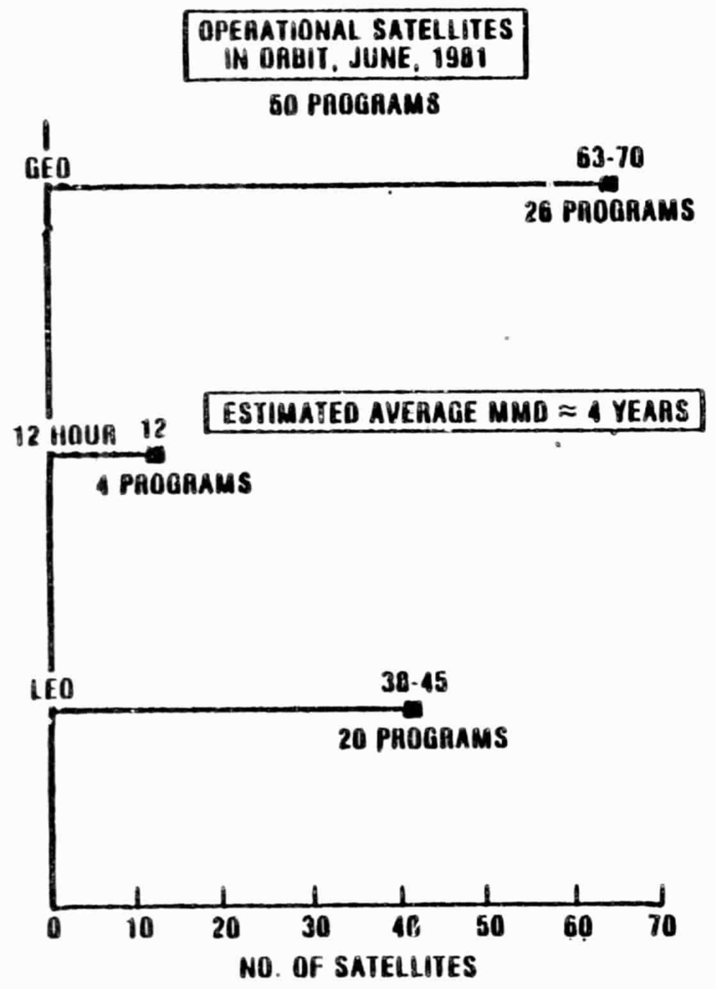
SYSTEM AVAILABILITY ⟹ MISSION ACCOMPLISHMENT

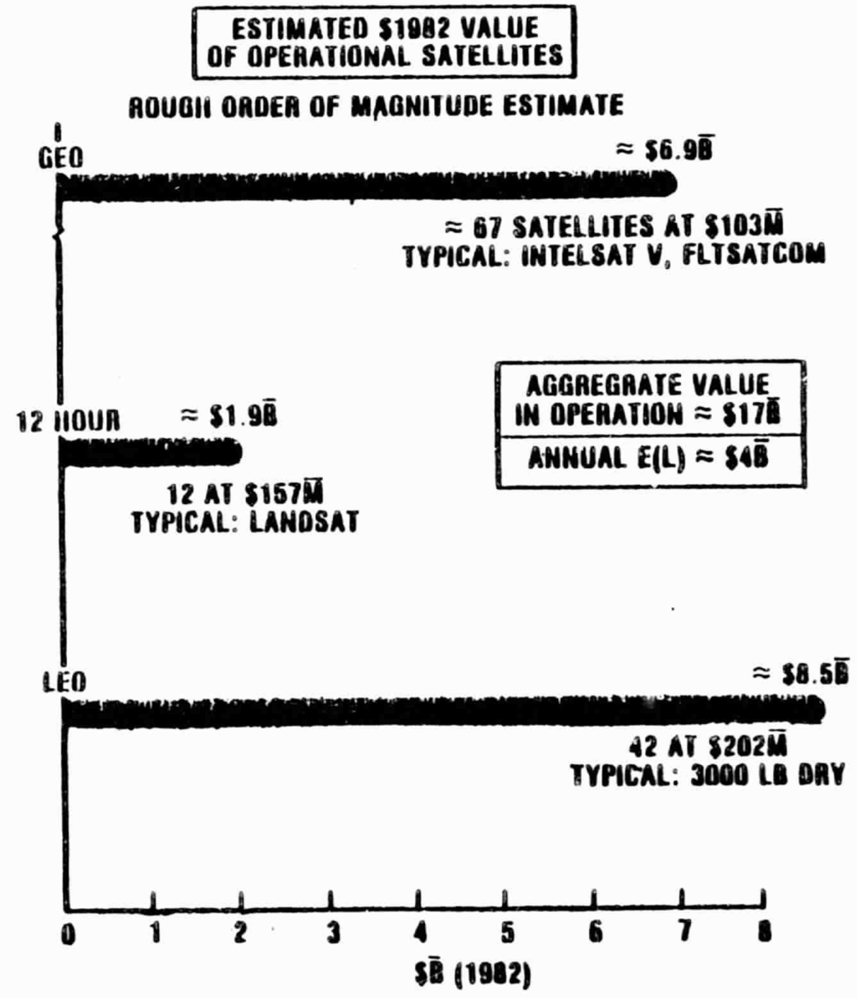


ESTIMATED ANNUAL LOSS OF OPERATIONAL EXPENDABLE SATELLITES

The magnitude of economic loss currently borne by the nation's space program budgets can be estimated conservatively at approximately $\$4\bar{B}_{82}$ per year. In the current American satellite population of approximately 120 satellites, 25% loss in value per year is realized through premature failure, wear-out and/or depletion of consumables. To the extent that satellite servicing can repair accrued failures, replace worn out elements, and/or replenish consumables, all or a part of the $\$4\bar{B}$ per year annual loss might be avoided.

ESTIMATED ANNUAL LOSS OF OPERATIONAL EXPENDABLE SATELLITES





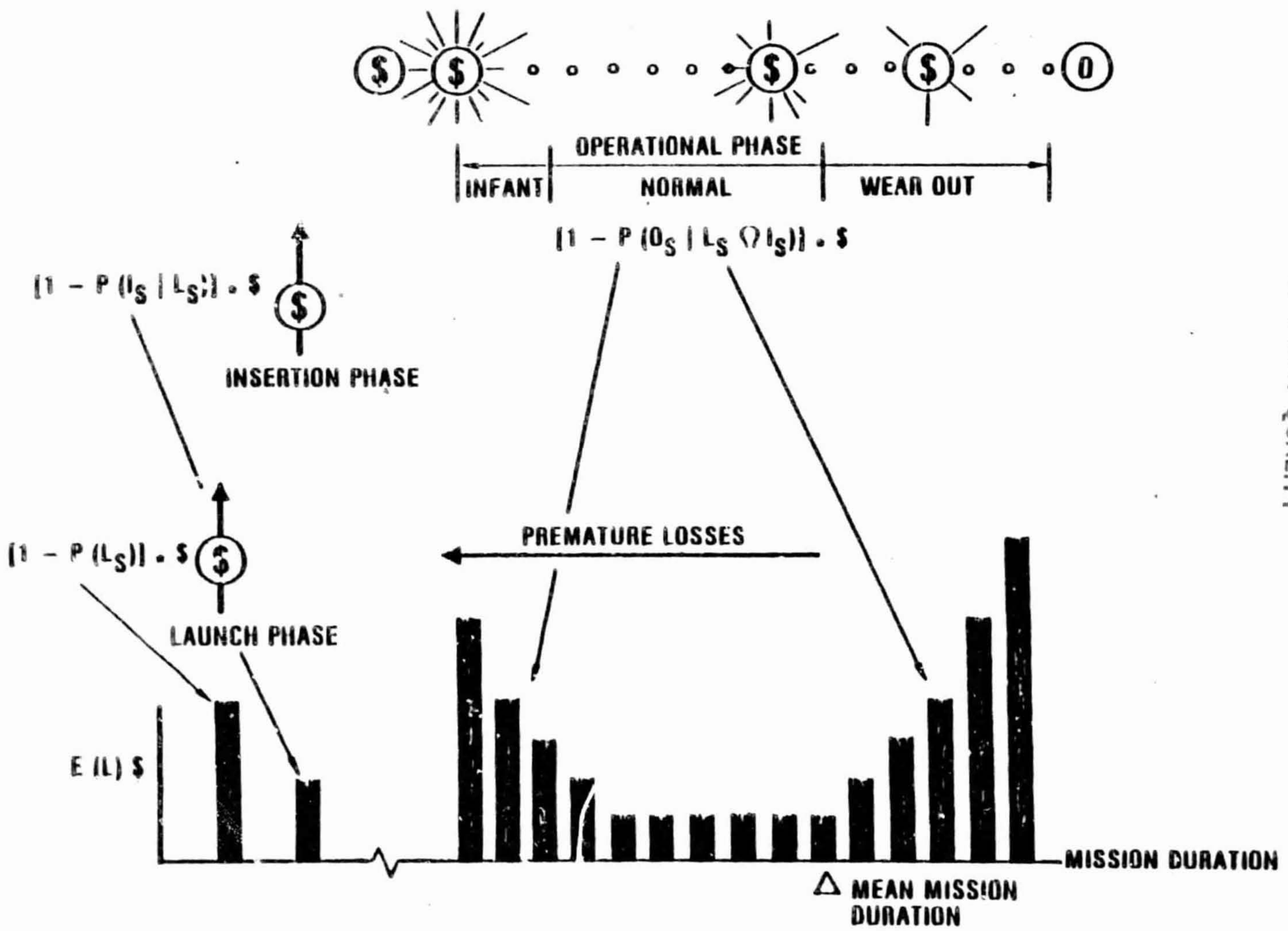
DATA: AEROSPACE CORP

92SSV126146

EXPECTED LOSS - REDUCTION IN SATELLITE VALUE DUE TO FAILURES

Space programs can suffer losses in any mission phase. Recent examples include loss of the Marecs B and Sirio 2 satellites due to launch system failure of Ariane 5; loss of a GPS satellite due to failure of an Atlas space launch vehicle; loss of an RCS Syncom satellite due to failure of the geosynchronous insertion stage; loss of the Solar Max Mission early in its operational life due to design-induced failure; partial loss of Insat 1A capability due to failure of its solar sail to deploy, followed by complete satellite loss due to failure of its attitude control system; and potential partial loss of Landsat D function due to failure of the Ku-band antenna to deploy. Some, or all, future failures can be corrected through on-orbit servicing.

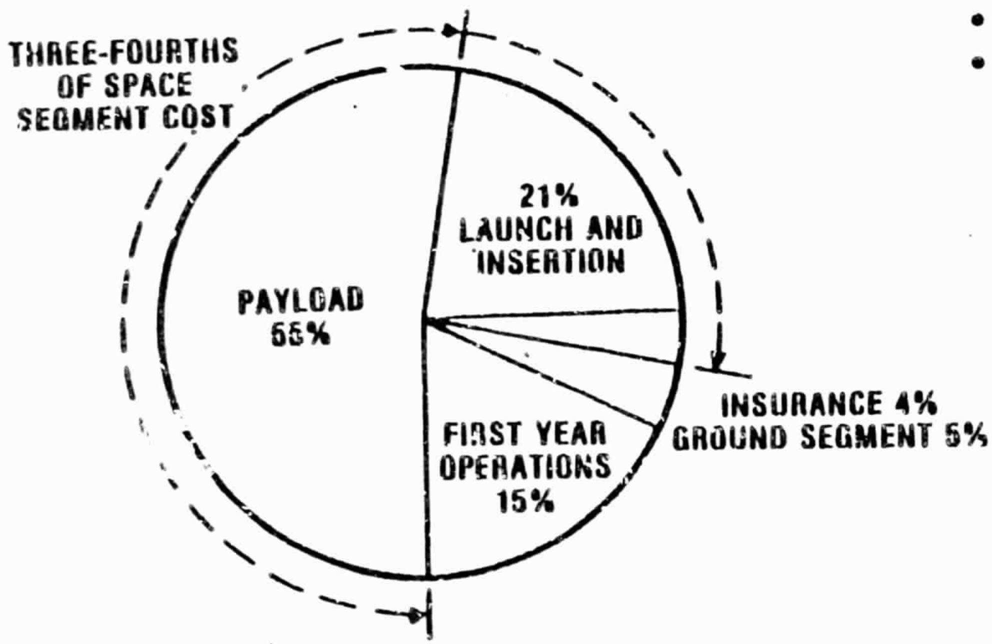
EXPECTED LOSS EQUALS REDUCTION IN SATELLITE VALUE DUE TO FAILURES



MAJOR COST ELEMENTS - COMMUNICATIONS SATELLITES

Payload costs drive total mission costs in most space systems. Therefore, reducing payload-related expenditures can significantly improve the cost/benefit ratio realized by commercial, NASA and DoD programs.

MAJOR COST ELEMENTS — COMMUNICATION SATELLITES



- PAYLOAD IS MAJOR COST DRIVER
- INSURANCE ≈ 6% SPACE SEGMENT
  - ✓ LAUNCH RISK
  - ✓ INSERTION RISK
  - ✓ OPERATION RISK

- TRANSPONDER VALUE-IN-USE ⩾ \$5M (1982) PER YEAR ≈ \$570 PER TRANSPONDER PER HOUR, GTE GSTAR

SOURCE: SUMMARY OF APPLICATIONS FOR DIRECT BROADCAST SATELLITES FILED WITH FCC

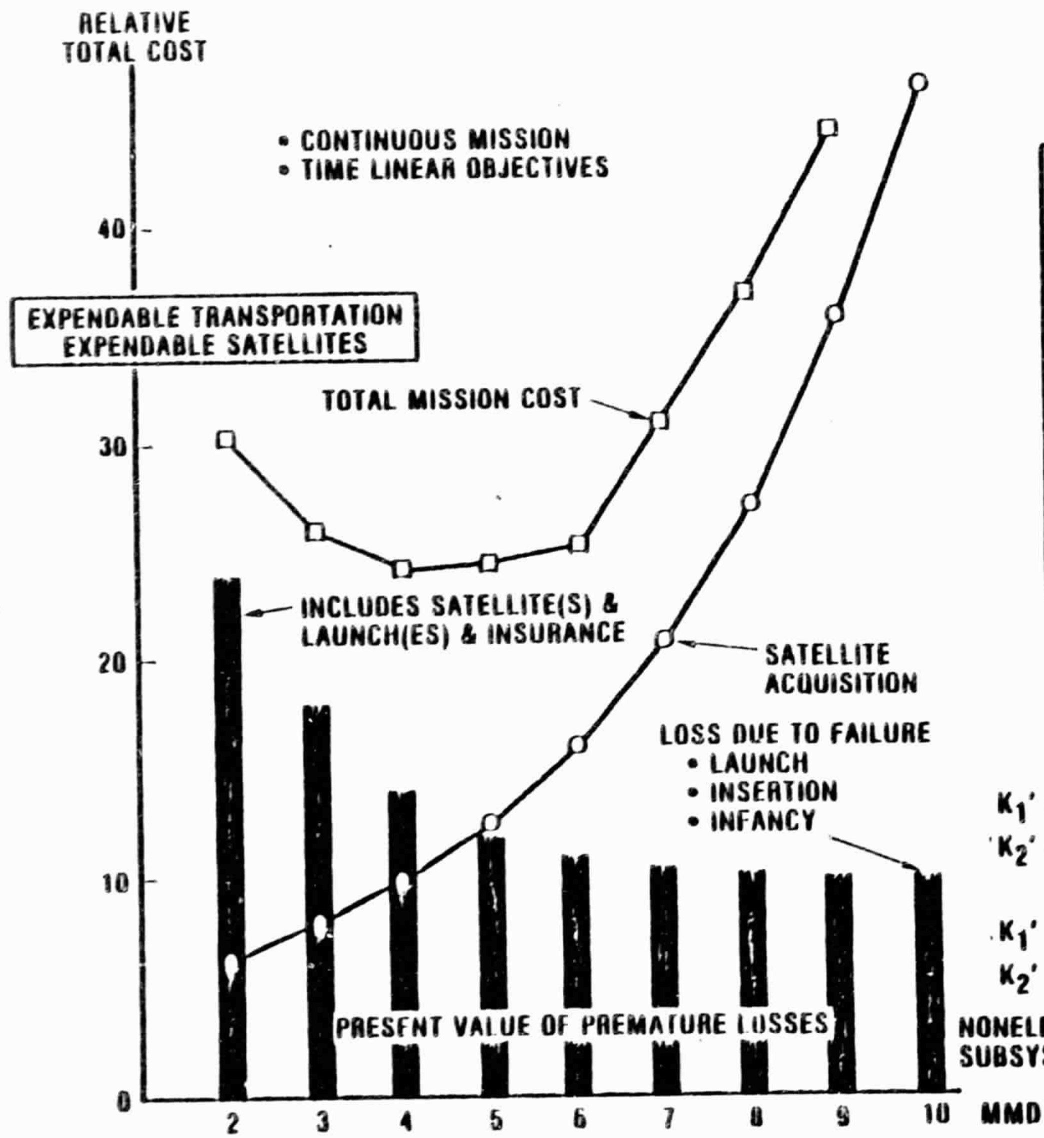
92SSV126149

SATELLITE DESIGN LIFE - TOTAL MISSION COST

Total mission costs are comprised of satellite acquisition costs and expected losses throughout the program. Satellite acquisition costs vary directly with satellite design lifetime; expected loss costs, when spares-associated costs are included, vary inversely with satellite design life. The combined total cost function can be quantified with parametric cost estimating relationships and subsequently optimized.

C-3

SATELLITE DESIGN LIFE — TOTAL MISSION COST



SATELLITE ACQUISITION COST
$q = 4$

MMD	K_1'	K_2'	$K_1' + K_2' \cdot q^{0.926}$
2	2.80	1.0	6.41
3	3.11	1.32	7.88
4	3.48	1.76	9.84
5	3.92	2.37	12.47
6	4.44	3.21	16.01
7	5.05	4.36	20.79
8	5.78	5.95	27.25
9	6.64	8.13	36.00
10	7.66	11.14	47.89

K_1' = NONRECURRING RDT&E,
K_2' = THEORETICAL FIRST UNIT

$K_1' = K_1 \cdot [0.4 + 0.6 \cdot e^{(0.17\,MMD - 0.34)}]$
$K_2' = K_2 \cdot [0.15 + 0.85 \cdot e^{(0.32\,MMD - 0.64)}]$

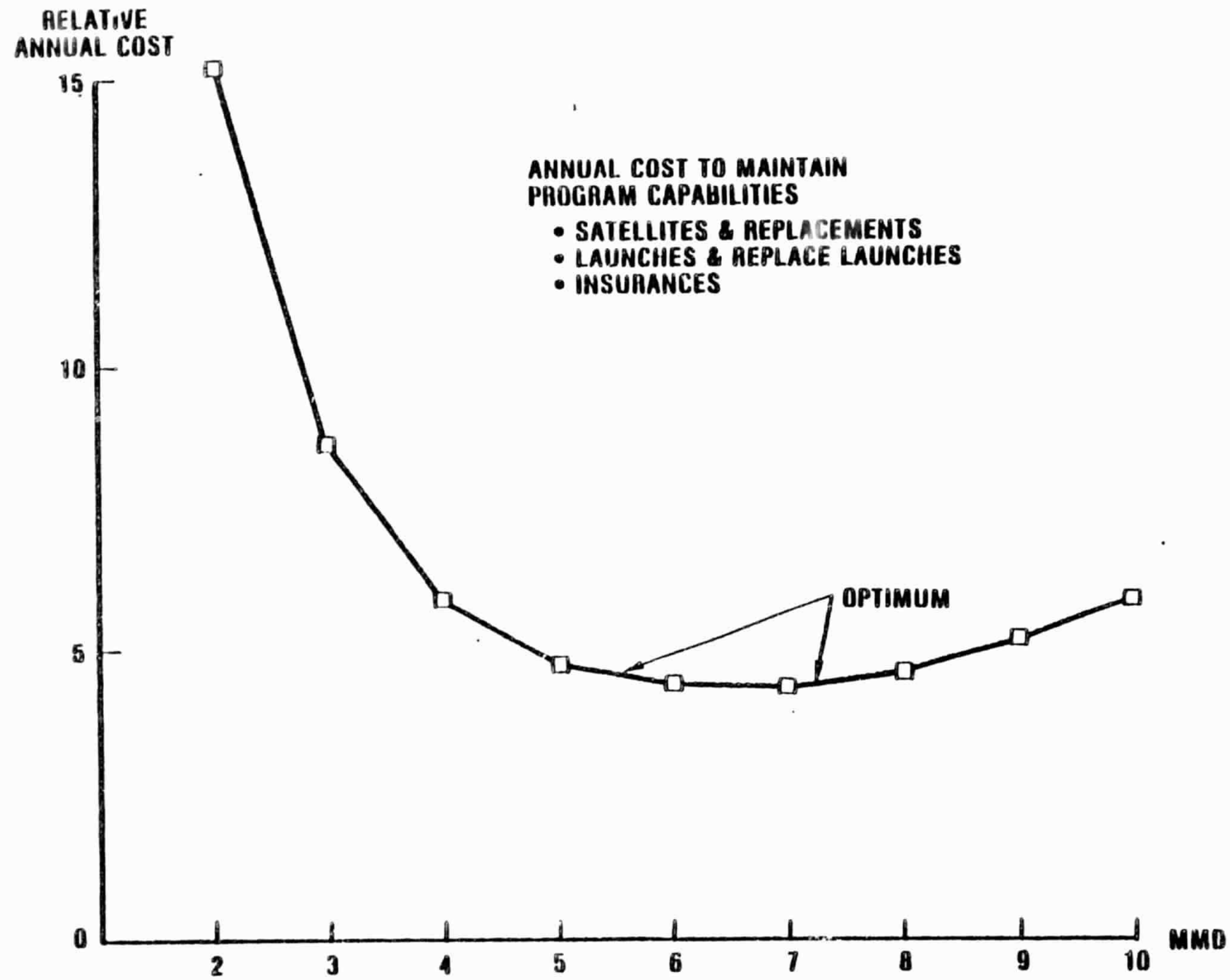
NONELECTRONIC SUBSYSTEMS — COST FACTORS — ELECTRONIC SUBSYSTEMS

92SSV126149

SATELLITE DESIGN LIFE VERSUS TOTAL MISSION COST PER YEAR

Total annual mission costs are optimized at the lowest combination of annual acquisition cost and annual expected loss.

SATELLITE DESIGN LIFE VERSUS TOTAL MISSION COST PER YEAR



92SSV126150

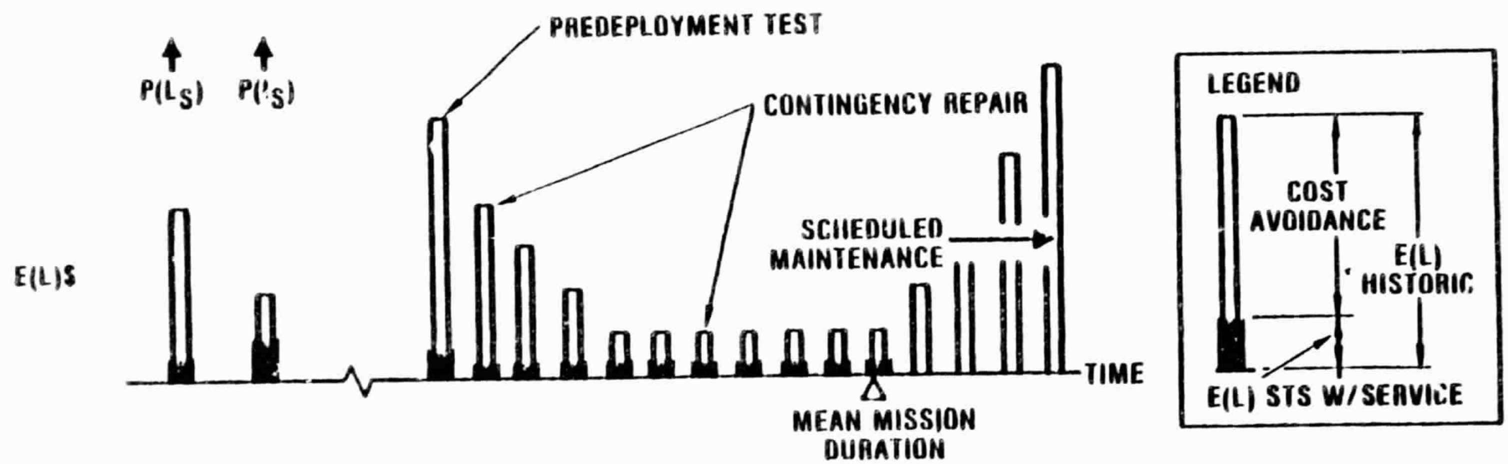
POTENTIAL AREA FOR ECONOMIC BENEFIT: SERVICING

Servicing provides economic benefits by reducing satellite system acquisition costs and by reducing program space transportation costs.

POTENTIAL AREAS FOR ECONOMIC BENEFIT: SERVICING

- LOWER SATELLITE PROGRAM ACQUISITION COSTS
  - FEWER (IF ANY) SPARE SATELLITES REQUIRED
  - LOWER INTERNAL SATELLITE REDUNDANCY NEEDED
- LOWER PROGRAM TRANSPORTATION CHARGES
  - FEWER ON-ORBIT SATELLITES = FEWER LAUNCHES AND INSERTIONS
  - RELIABLE TRANSPORT TO ORBIT = FEWER LOSSES ON LAUNCH, INSERTION
  - ON-ORBIT PREDEPLOYMENT TEST = LOWER INFANT MORTALITY LOSS

$$P(O_S \mid L_S \cap I_S)$$

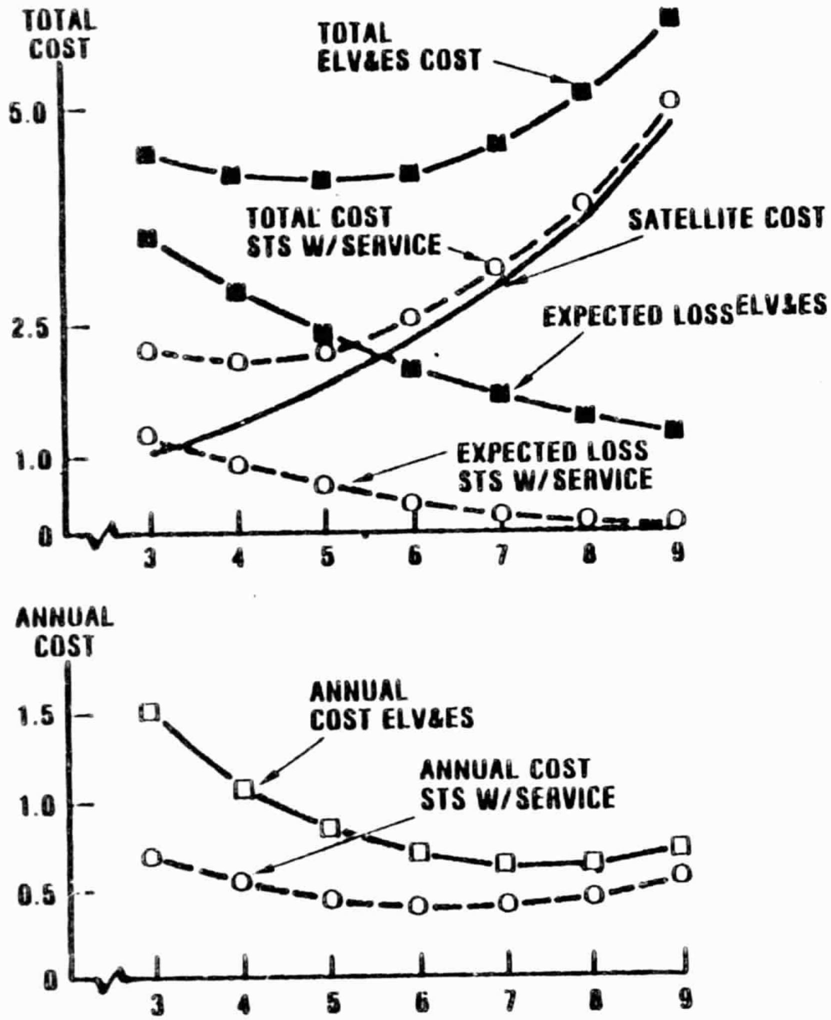


92SSV126151

RELIABLE PAYLOAD DELIVERY, PAYLOAD SERVICING, LEAD TO LOWER MISSION COST

The Space Shuttle lowers satellite system costs by reducing launch losses, insertion losses, and infant mortality losses; TMS can lower satellite system costs by reducing (correcting) infant mortality losses, operational phase losses, and wear out losses.

RELIABLE PAYLOAD DELIVERY, PAYLOAD SERVICING LEADS TO LOWER MISSION COST



—□— **EXPENDABLE LAUNCH VEHICLES**

- 4-6% SATELLITES LOST DUE TO LAUNCH OR INSERTION FAILURES
- INFANT MORTALITY (LAUNCH-INDUCED OR DESIGN) FAILURES CANNOT BE RECOVERED

—□— **EXPENDABLE SATELLITES**

- HIGH COST DESIGN & PRODUCTION
  - REDUNDANCY HEDGING
  - QUALITY & TESTING
- PREMATURE LOSS ($) HIGH

—O— **RELIABLE STS W/SERVICING**

- LOWER LOSS = COST AVOIDANCE

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92SSV126152

EXPECTED LOSS SIMULATION METHODOLOGY

Satellite system losses in three reference programs were measured by simulation based on relevant subsystem characteristics, failure modes and effects parameters, and documented satellite cost estimating relations.

SPACE SHUTTLE ORBITER

EXPECTED LOSS SIMULATION METHODOLODY

SATELLITE DESCRIPTORS

- o COMMUNICATIONS GEO
- o SUBSYSTEM PARAMETERS
  - o WEIGHT, POWER
  - o MMD, α, β
- o PROGRAM QUANTITY

REFERENCE SERVICE MISSIONS

- GEO COMSAT
- POLAR LANDSAT
- LEO ASTRONOMIC OBSERVATORY

- VERIFY AFSD COST MODEL

P(Ls)	P(Is)	MMD	TOTAL	EXPECTED LOSS									
				LAUNCH	INSERT	INFANT	1	2	000	MMD	000		10
0.97	0.97	4	$200.0	$6.0	$6.0	$12.0	$2.0	$8.0	$16.0	$20.0	18.0	000	0.0
PV E(L) @ 0.25			$120.0	6.0	6.0	12.0	1.6	5.1	8.2	8.2	5.9	000	0.0
% OUTLAY THRU MMD			23.6	3.0	3.0	6.0	0.1	2.6	4.1	4.1	3.0	000	0.0

	SATELLITE ACQUISITION				PROGRAM	PV E(LOSS)		MISSION COST	
DESIGN MMD	NON-RECCUR	1ST UNIT	TOTAL	AVERAGE	TOTAL	TOTAL	ANNUAL	TOTAL	ANNUAL
3	240	85	580	145	720	120	40	840	280
4	280	100	640	160	800	120	30	920	230
5	350	125	820	205	1000	130	26	1130	226
6	450	160	1040	260	1240	140	23	1380	230
7	0	0	0	0		0	0	0	0
8	0	0	0	0		0	0	0	0
9	0	0	0	0		0	0	0	0

COMMUNICATIONS SATELLITE REFERENCE MISSION

Communications satellites, the least complex and most durable of generic satellite classes, can be expected to cost approximately $\$200\overline{M}_{82}$ each by the mid-1990's.

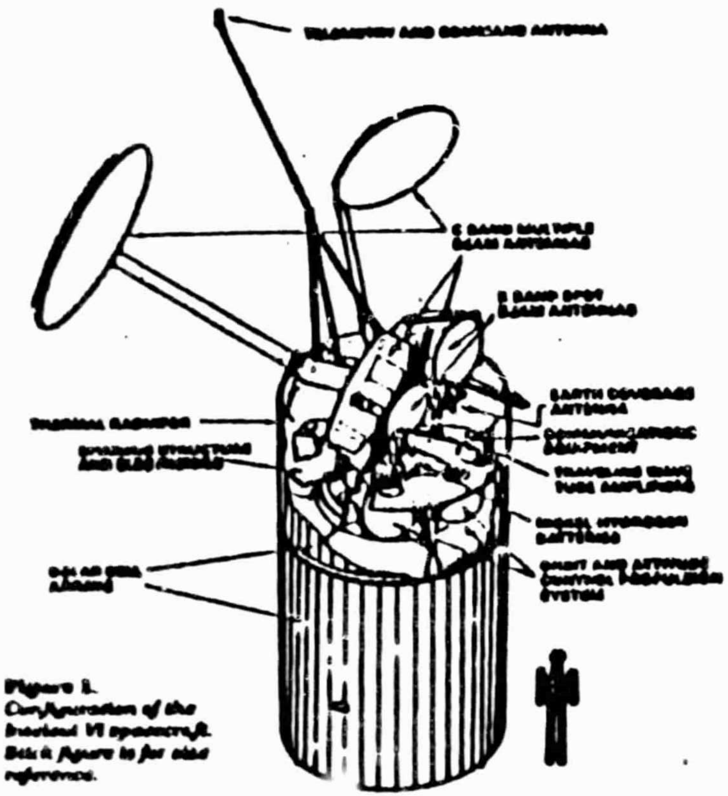


Figure 1. Configuration of the Intelsat VI spacecraft. Stick figure is for size reference.

CURRENT GEO POPULATION: 71-75
INTELSAT VI $700 M, 5 SATELLITES
3,918 LBS BOL IN GEO

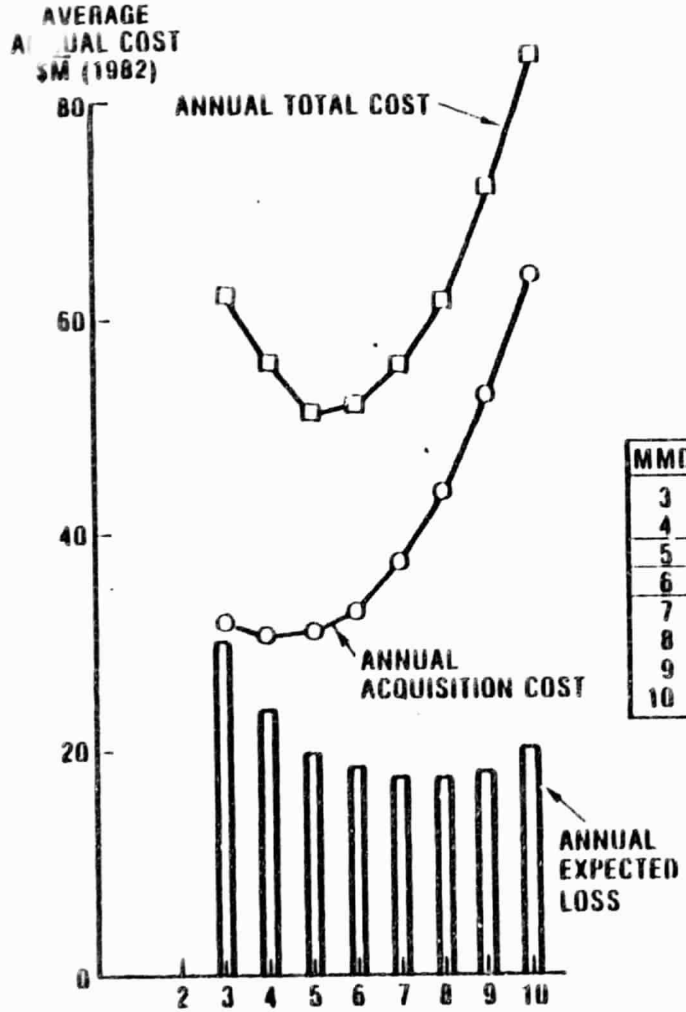
NEXT GENERATION COMSAT c. 1990's

o STRUCTURE & THERMAL	1,190 LBS
o TELE, TRACK & COMMAND	111
o COMMUNICATIONS	1,206
o ATTITUDE CONTROL	560
o ELECTRICAL POWER	550 4KW
o MISCELLANEOUS	215
o DRY MASS	3,832
o PROPELLANT ACS	888
o ON-ORBIT MASS	4,720 LBS
• PROGRAM QUANTITY =	12

POTENTIAL SERVICING BENEFIT - GEO COMMUNICATIONS SATELLITE

At an optimized design life of 5-6 years, expected losses for a typical "next generation" comsat approximate $\$20\overline{M}_{82}$ per year. A "rough order of magnitude estimate of recurring annual loss in geostationary orbit exceeds $\$3\overline{B}_{82}$ per year.

POTENTIAL SERVICING BENEFIT -- GEO COMMUNICATIONS SATELLITE ($M 1982)



MMD	SATELLITE AVERAGE COST	SATELLITE ANNUAL COST	ANNUAL EXPECTED LOSS $P(L_S \cap I_S) = 0.94$	AVERAGE ANNUAL TOTAL COST	SATELLITE ANNUAL COST	ANNUAL EXPECTED LOSS $P(L_S \cap I_S) = 1.00$	AVERAGE ANNUAL TOTAL COST
3	95.8	31.9	36.4	68.3	31.9	30.6	62.5
4	121.2	30.3	28.5	58.8	30.3	24.6	54.3
5	156.1	31.2	24.6	55.8	31.2	20.0	51.2
6	203.6	33.9	22.9	56.8	33.9	18.8	52.7
7	269.1	38.4	22.2	60.6	38.4	17.6	56.0
8	357.1	44.6	23.7	68.3	44.6	18.0	62.6
9	479.6	53.3	23.7	77.0	53.3	19.5	72.8
10	647.4	64.7	27.5	92.2	64.7	21.0	85.7

POTENTIAL SERVICING BENEFIT ≈ $20M (1982) PER COMSAT PER YEAR

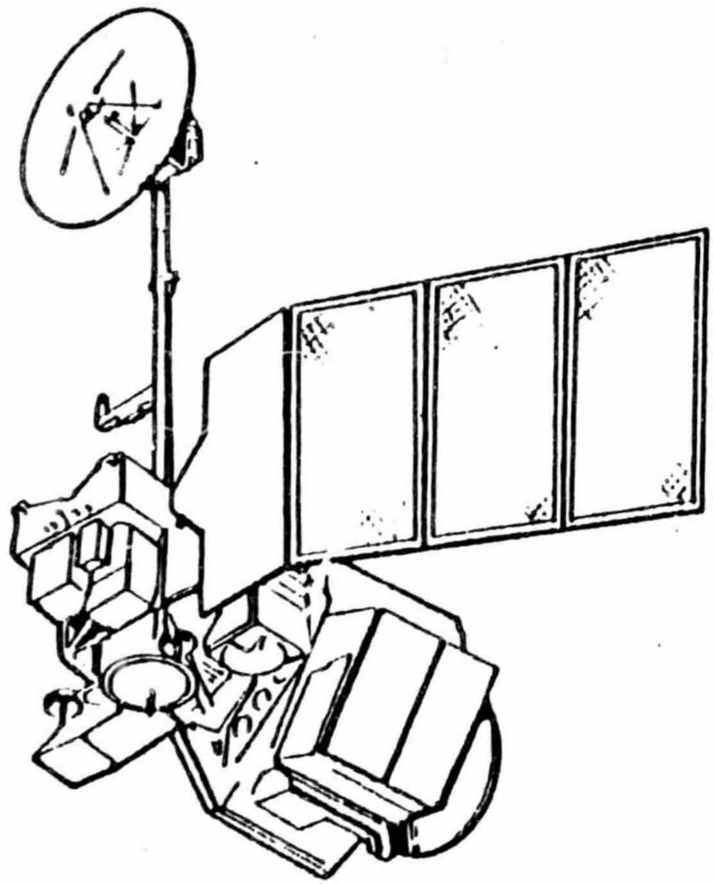
- POTENTIAL MID-1990'S GEO POPULATION 135-160 SATELLITE (EQUIVALENTS)

92SSV126154

POLAR SATELLITE REFERENCE MISSION

Earth observation satellites, more complex and expensive but less durable than communications satellites due to specialized sensors and lower production quantities, can be expected to cost over \$300$\overline{M}_{82}$ each by the mid-1990's.

POLAR SATELLITE REFERENCE MISSION



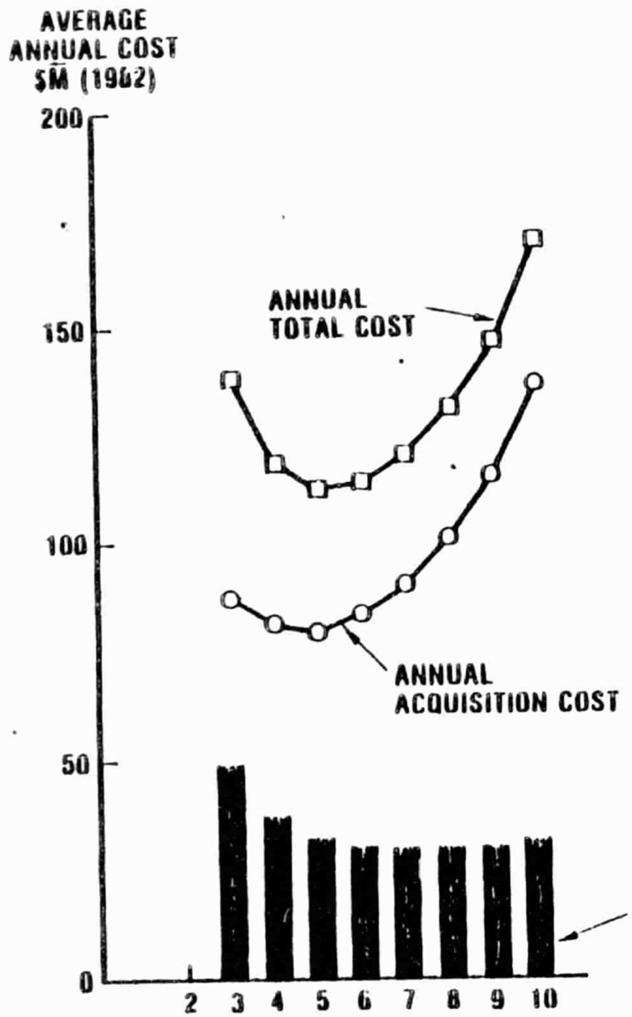
CURRENT POLAR POPULATION: 12
LANDSAT D&D', $505 M
≈ 4,000 LBS BOL IN POLAR

o STRUCTURE & THERMAL	718 LBS	
o TELE. TRACK & COMMAND	726	
o SENSOR PACKAGES	660	
o ATTITUDE CONTROL	409	
o ELECTRICAL POWER	778	2.2 KW
o MISCELLANEOUS	157	
o DRY WEIGHT	3,448 LBS	
o PROPELLANT ACS	517	
o ON-ORBIT WEIGHT	3,965 LBS	
• PROGRAM QUANTITY	= 2	

POTENTIAL SERVICING BENEFIT - POLAR EARTH OBSERVATION SATELLITE

Front-end budgetary constraints frequently force sub-optimal design lifetimes in the earth observation satellite class, and annual losses of \$40 to $\$50\overline{M}_{82}$ per satellite per year are realistic. Conservative estimates of aggregate annual economic loss in Polar orbit run upwards from $\$600\overline{M}$ per year in the mid-1990's.

POTENTIAL SERVICING BENEFIT — POLAR EARTH OBSERVATION SATELLITE



MMD	SATELLITE AVERAGE COST	SATELLITE ANNUAL COST	ANNUAL EXPECTED LOSS $P(L_S \cap I_S) = 0.94$	AVERAGE ANNUAL TOTAL COST	ANNUAL EXPECTED LOSS $P(L_S \cap I_S) = 1.00$	AVERAGE ANNUAL TOTAL COST
3	266.4	88.8	52.6	141.4	49.7	138.5
4	323.2	80.8	43.3	124.1	36.0	118.8
5	398.1	79.6	36.8	116.4	33.3	112.9
6	498.8	83.1	33.8	116.9	30.7	113.8
7	632.7	90.4	33.7	124.1	31.2	121.6
8	814.9	101.9	33.3	134.6	30.2	132.1
9	1057.6	117.5	35.6	153.1	30.1	147.6
10	1383.2	138.3	40.1	178.4	32.3	170.6

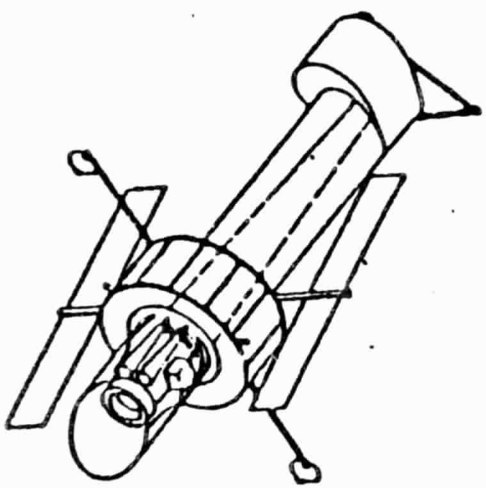
POTENTIAL SERVICING BENEFIT
≈ $30-35M̄ PER SATELLITE PER YEAR

- POTENTIAL MID-1990'S POPULATION
  18-20 SATELLITES (AVERAGE OPERATIONAL)
  INCLUDING DOD PROGRAMS

LEO, 28.5° ASTRONOMIC OBSERVATORY REFERENCE MISSION

Astronomic observatory class satellites, due to their unique designs, massive size and enormous complexity, are the most expensive of current space asset types; unit costs may approach or exceed a billion dollars by the mid-1990's.

LEO, 28.5^{0} ASTRONOMIC OBSERVATORY REFERENCE MISSION



CURRENT LEO POPULATION: 38-45
SOLAR MAX, $216 $\bar{M}$
≈ 5093 LBS IN LEO

MID - 1990's REPRESENTATIVE: AXAF

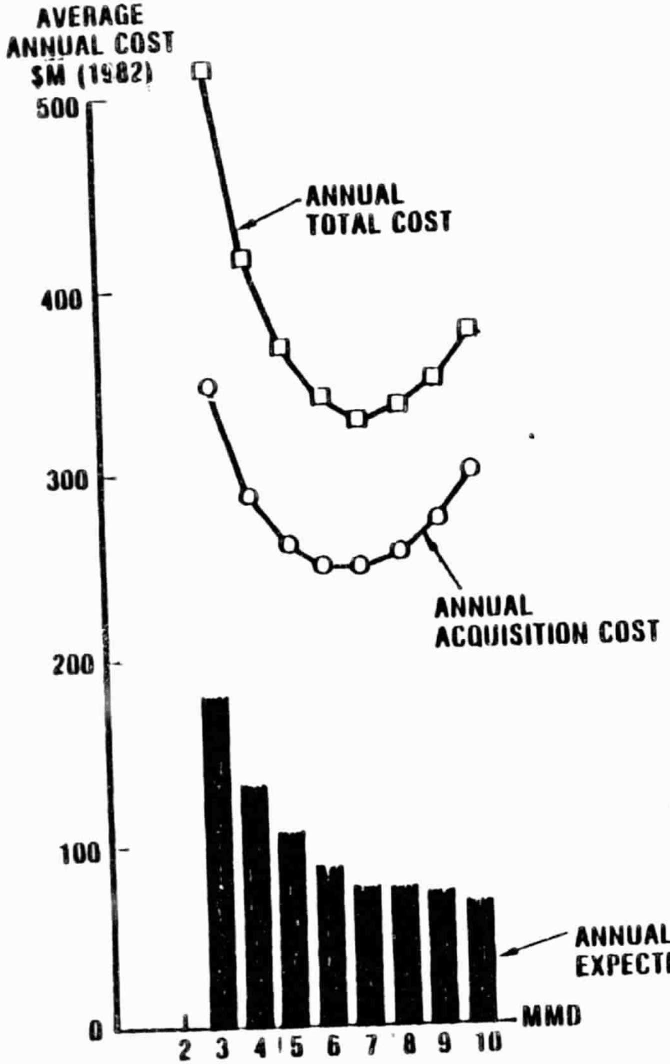
o STRUCTURE & THERMAL	12,318 LBS	
o TELE, TRACKING & COMMAND	1,560	
o X-RAY OPTICS	3,030	
o ATTITUDE CONTROL	1,507	
o ELECTRIC POWER	3,520	2.0 KW
o MISCELLANEOUS	1,107	
o DRY WEIGHT	23,042 LBS	

- PROGRAM QUANTITY = 1

POTENTIAL SERVICING BENEFIT - LEO SATELLITE, 28.5°

The huge front-end acquisition cost associated with the astronomic observatory class of satellite forces short-life (thus, sub-optimal) designs. Therefore, the expected annual loss is likely to be much higher than the $\$80\bar{M}_{82}$ per satellite per year potential servicing benefit for an optimally designed LEO astronomic observatory. The gross potential benefit at LEO in the mid-1990's, with a satellite population comprised of both astronomic and earth scientific observatories, exceeds $\$2\bar{B}_{82}$ per year.

POTENTIAL SERVICING BENEFIT — LEO, SATELLITE (28.5°)



MMD	SATELLITE AVERAGE COST	SATELLITE ANNUAL COST	ANNUAL EXPECTED LOSS $P(L_S \cap I_S)=0.94$	AVERAGE ANNUAL TOTAL COST	ANNUAL EXPECTED LOSS $P(L_S \cap I_S)=1.00$	AVERAGE ANNUAL TOTAL COST
3	1038.7	346.2	194.6	540.8	183.2	529.4
4	1154.9	288.7	143.1	431.8	135.5	424.2
5	1303.2	260.6	120.9	381.5	108.1	368.7
6	1495.2	249.2	103.8	353.0	91.9	341.1
7	1740.5	248.6	94.3	342.9	80.7	329.3
8	2059.7	257.5	87.4	344.9	80.8	338.3
9	2476.8	275.2	88.3	363.5	78.2	353.4
10	3027.7	302.8	86.2	389.0	75.6	378.4

POTENTIAL SERVICING BENEFIT
≈ $80M PER LEO OBSERVATORY PER YEAR

- POTENTIAL MID-1990'S POPULATION
  - ✓ 6 LEO ASTRONOMIC OBSERVATORY CLASS
  - ≥ 30 TOTAL LEO AT 28.5°

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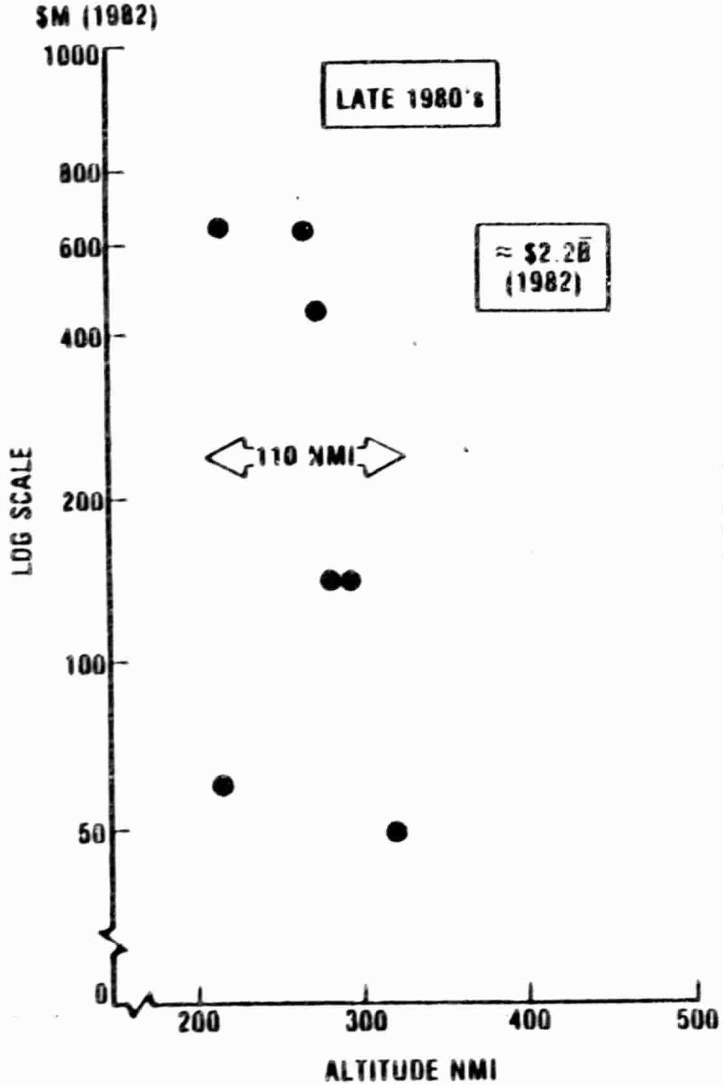
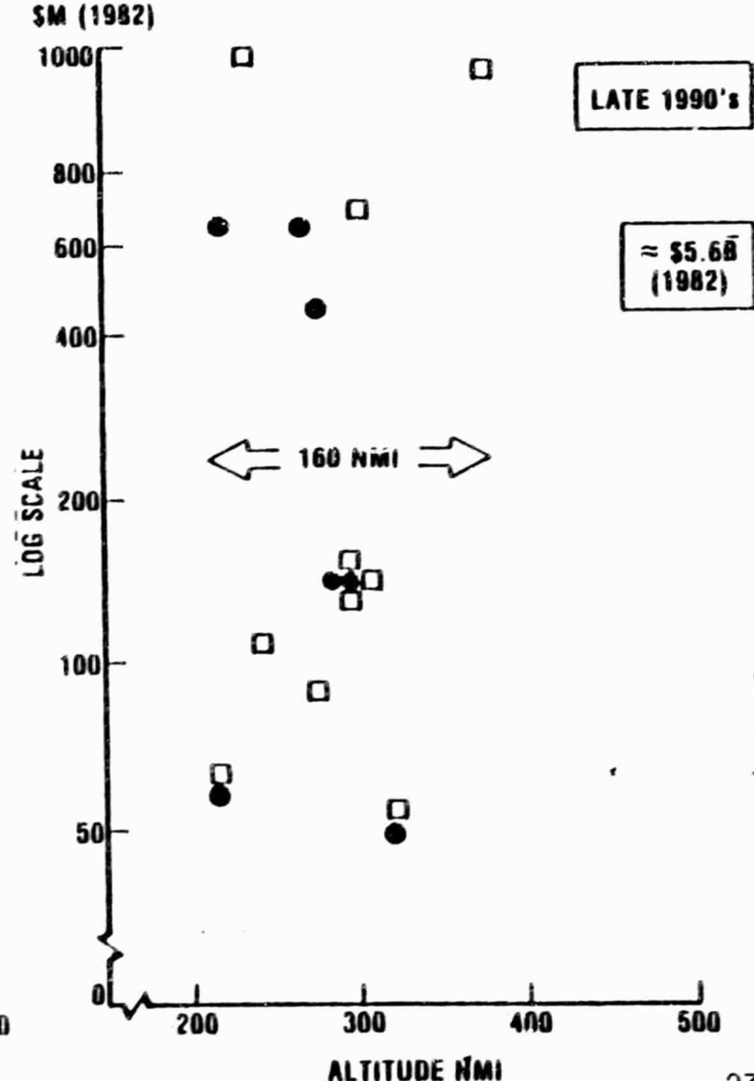
SERVICEABLE SATELLITE PROJECTIONS (LEO, 28.5^{o})

Substantial serviceable-design satellite population growth will be experienced in all LEO inclinations throughout the 1990's, with the preponderance of potential servicing engagements in the 200-400 n.mi. altitude region.

SERVICEABLE SATELLITE PROJECTIONS (LEO, 28.5°)





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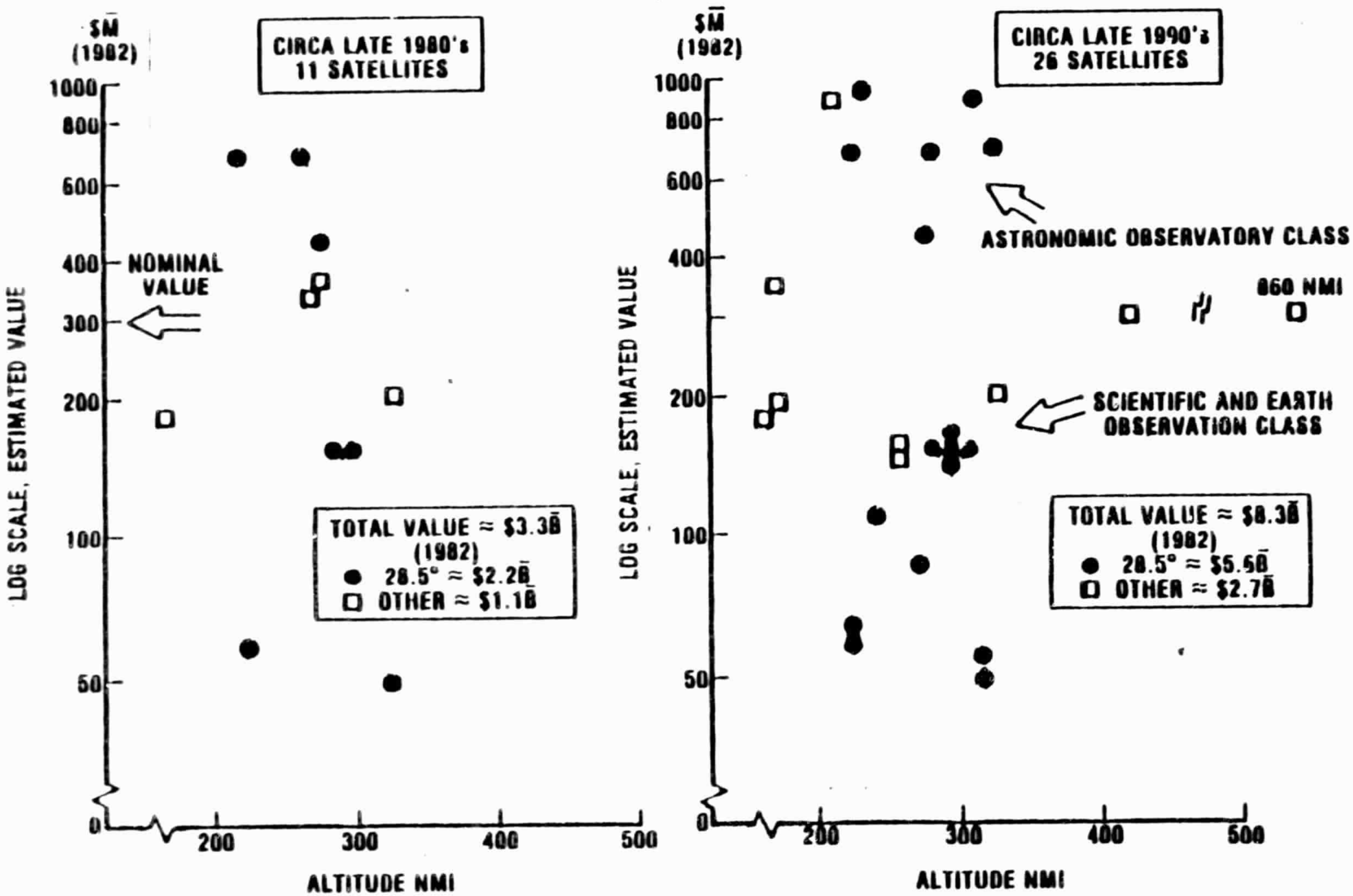
SERVICEABLE DESIGN SATELLITE POPULATION LEO (NON-POLAR, NON-DoD PROGRAMS)

The population of satellites designed for servicing will grow rapidly in the 28.5^{o} orbital plane across the 1990's, with particular concentration of capital in the astronomic observatory class which (almost) must be designed for periodic maintenance.

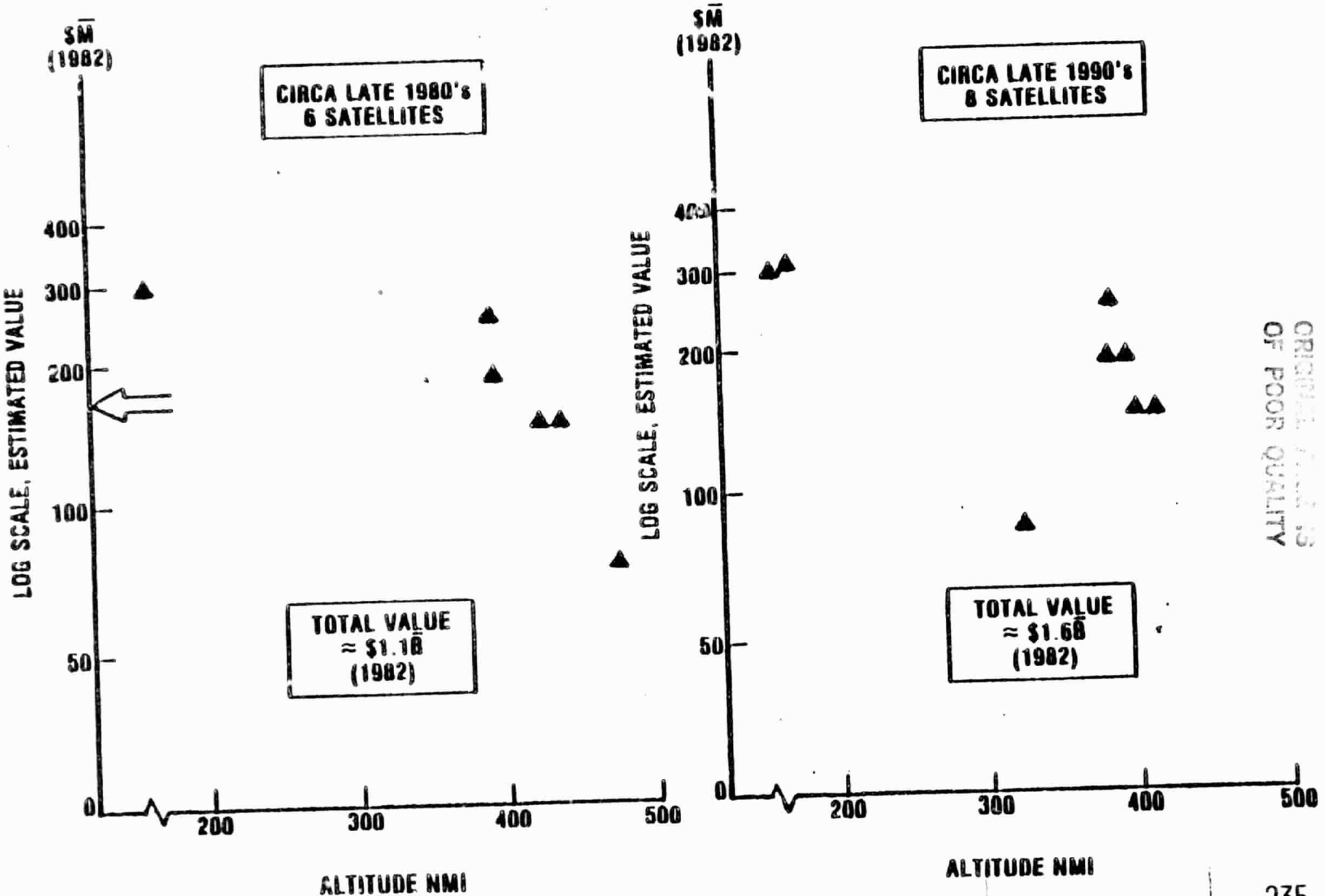
SERVICEABLE — DESIGN SATELLITE POPULATION, LEO (NON-POLAR) (NON-DOD PROGRAMS)



SERVICEABLE DESIGN SATELLITE POPULATION, POLAR (NON-DoD PROGRAMS)

Lower acceptance of the "design for service" philosophy will be experienced at polar LEO inclinations than at 28.5° due to the high transportation cost of TMS servicing from WTR and the lower concentration of capital. Concept acceptance by the DoD, the dominant payload sponsor in this orbital plane, could expand the projected serviceable satellite population.

SERVICEABLE — DESIGN SATELLITE POPULATION, POLAR (NON-DOD PROGRAMS)



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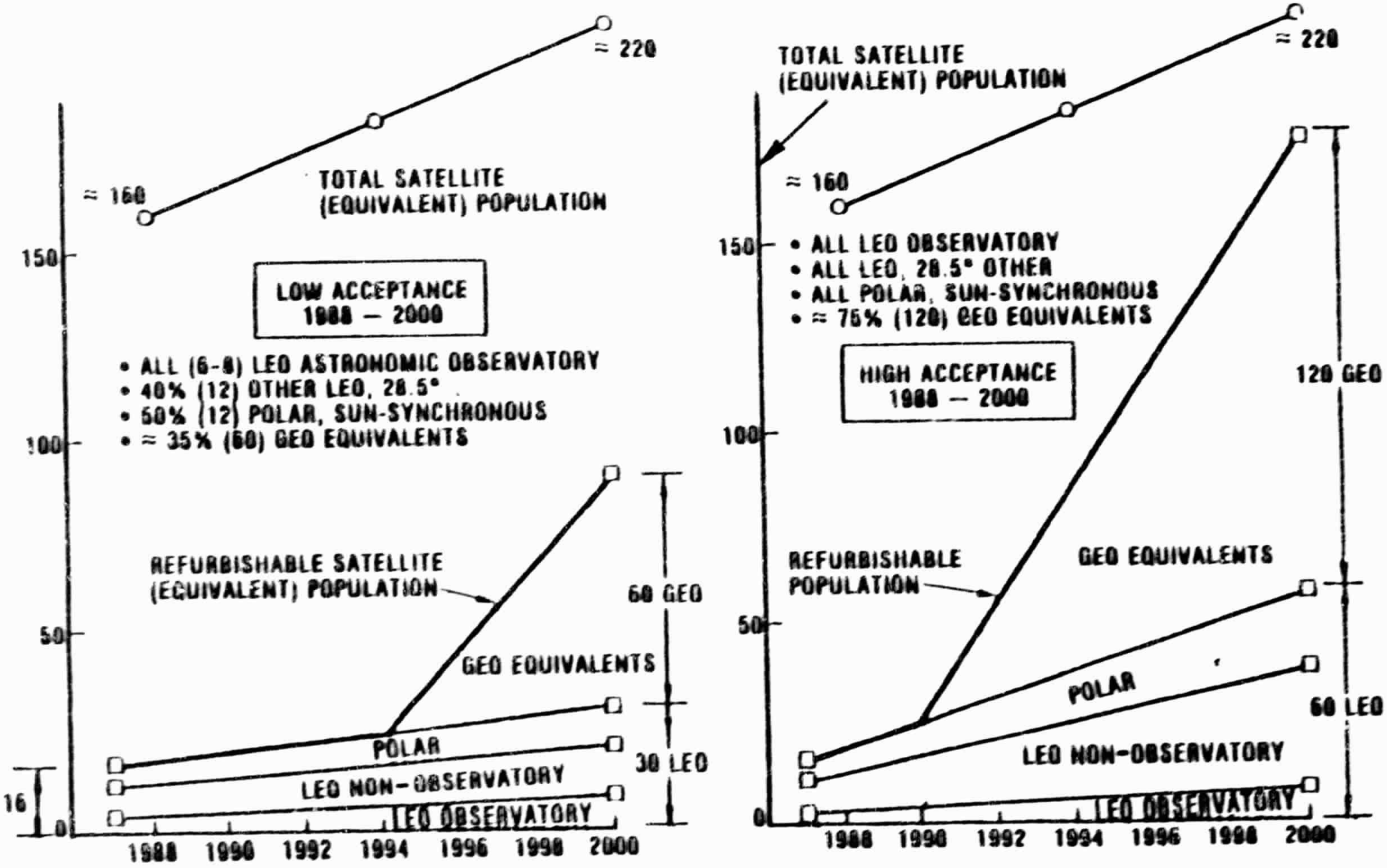
SERVICEABLE SATELLITE POPULATION PROJECTIONS

Aggregate serviceable satellite population growth across the 1990's depends on a significant change in payload design philosophy which, in turn, is wholly contingent upon proven economic advantage and demonstrated technological capability. Acceptance of the "design for service" philosophy will occur first in the NASA's own astronomic observatory programs and spread subsequently to other high-value programs using the 28.5° inclination. Polar orientation and (particularly) geosynchronous program users will be slower to adopt a new payload design philosophy; GEO acceptance will be enhanced by platforms and/or clusters, and is completely contingent on both LEO and GEO demonstrations of technological capability and economic advantage.

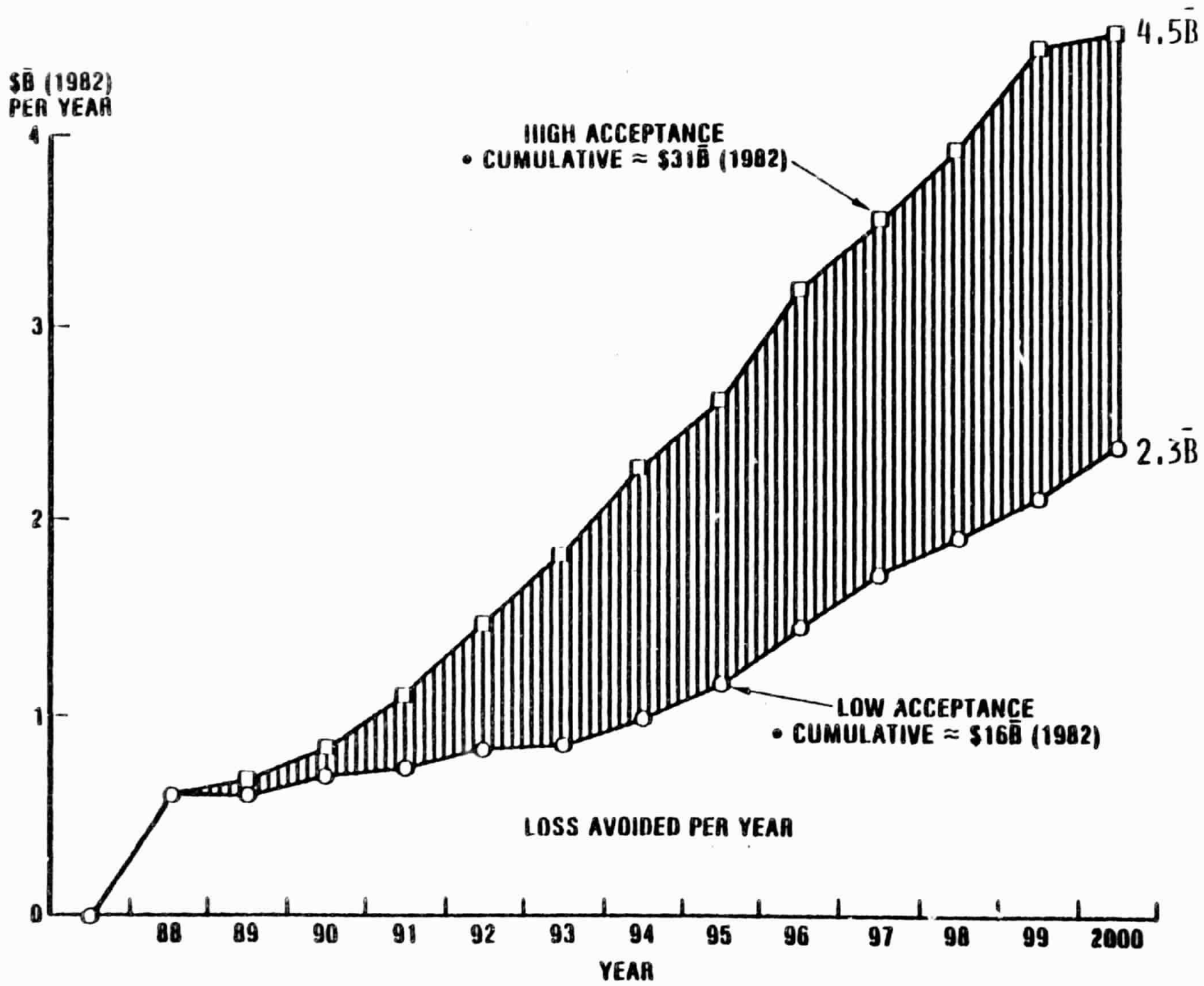
SERVICEABLE SATELLITE POPULATION PROJECTIONS



POTENTIAL LOSS AVOIDANCE BY YEAR: SATELLITE SERVI NG

Cumulating the potential annual servicing benefits across the low and high acceptance models yields the aggregate economic loss (waste) to the nation which could be avoided by continuous maintenance of all those satellites which are designed for service. Estimates of the potential pay-off range from \$2 + $\bar{B}_{82}$ per year to over \$4$\bar{B}_{82}$ per year by the end of the century.

POTENTIAL LOSS AVOIDANCE BY YEAR: SATELLITE SERVICING



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- SATELLITE DEPLOYMENT/RETRIEVAL
- SATELLITE SERVICING
- $\boxed{\text{• TMS ACQUISITION \& OPERATIONS COST}}$
- TMS NET BENEFITS ASSESSMENT

COST/BENEFIT GROUNDRULES & ASSUMPTIONS

Independent cost estimates relating to TMS Life-Cycle Cost (LCC) are based on statistical cost estimating relationships developed over a wide range of spacecraft programs, except as noted. TMS fleet size and per mission amortization have been calculated on the nominal TMS mission model; STS transportation charges are based on NASA's user charge per flight effective through September 30, 1988 for ETR launch services.

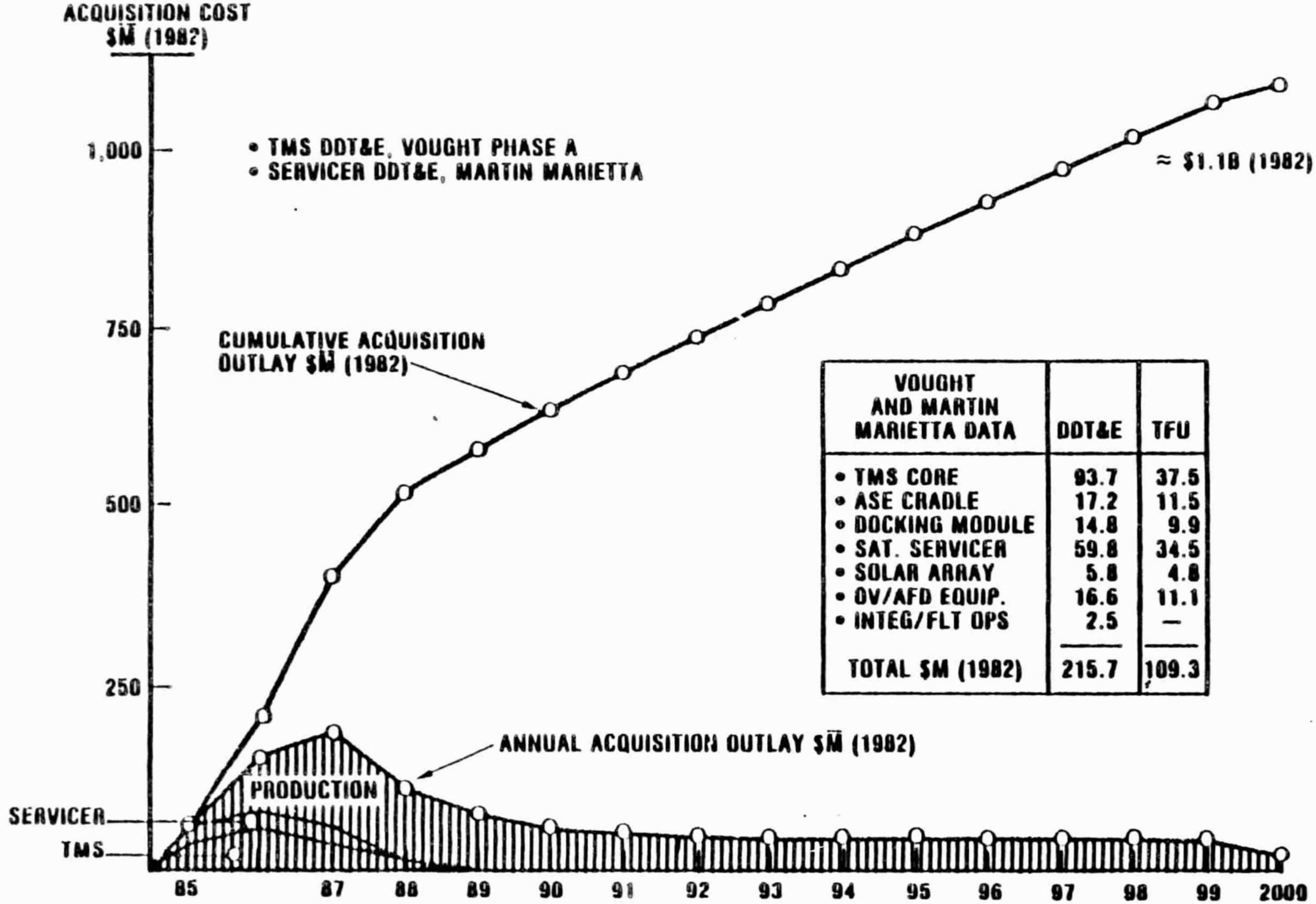
COST/BENEFIT GROUNDRULES & ASSUMPTIONS

- ALL COST ESTIMATES ADJUSTED TO CONSTANT <u>1982 DOLLARS</u>
- BASELINE <u>TMS</u> CONFIGURATIONS & <u>COST</u> ESTIMATES: VOUGHT PHASE 'A' REPORT
- "<u>SERVICER</u>" MODULE <u>COST</u> ESTIMATES: <u>MARTIN MARIETTA</u>
- INDEPENDENT COST ESTIMATES ARE PARAMETRIC
  - BASED ON <u>AFSD "UNMANNED SPACECRAFT COST MODEL"</u>; SD-TR-81-45, JUNE 1981
  - ADJUSTED (REDUCED BY 25%) TO ELIMINATE CHANGE-RELATED COSTS
- TMS ACQUISITION COST AMORTIZED OVER 218 TMS MISSIONS
- STS TRANSPORTATION COST BASED ON <u>$38M (1975$) PRICE</u> PER FLIGHT

BASELINE TMS ACQUISITION PROGRAMMATICS

TMS acquisition costs, extrapolated by application of learning curves to Vought and Martin-Marietta-supplied data, for a fleet of twelve (12) TMS units (4 ASE cradles and 4 sets of orbiter aft Flight Deck equipment) are estimated at $\$1.1\ B_{82}$ through the end of the century.

BASELINE TMS
ACQUISITION PROGRAMMATICS



VOUGHT AND MARTIN MARIETTA DATA	DDT&E	TFU
• TMS CORE	93.7	37.5
• ASE CRADLE	17.2	11.5
• DOCKING MODULE	14.8	9.9
• SAT. SERVICER	59.8	34.5
• SOLAR ARRAY	5.8	4.8
• OV/AFD EQUIP.	16.6	11.1
• INTEG/FLT OPS	2.5	—
TOTAL $M (1982)	215.7	109.3

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STS TRANSPORTATION COST DRIVES TMS PROGRAM COST

Three mission sharing scenarios were investigated:

- Mission sharing required for breakeven between the ground based TMS and integral spacecraft propulsion. This was found to occur at approximately 50% of the 218 launches in the nominal mission model, or 52% of the 210 non-GEO missions.
- Mission sharing deemed to be achievable: The 210 launches were reduced by 16 to a total of 194, or 64% shared missions consisting primarily of multiple engagements with single payload manifesting.
- Maximum mission sharing (100%), emphasizing multiple manifesting of TMS deployable payloads. This level of sharing, viewed as a goal, reduced launches to 121.

When maximum (100%) multiple manifesting of deployment missions and sharing of deploy/retrieve missions are included, which should be viewed as a goal, total TMS program Life-Cycle Costs (LCC) for the 413 payload engagements (218 TMS missions) are estimated at $\approx \$6.7\bar{B}_{82}$ for the ground-based concept. STS transportation charges, which are based on the $\$70.8\bar{M}_{82}$ per flight user charge throughout the analysis, comprise 83% of TMS LCC.

Without these additional shared missions, which leaves only half or 109 shared, LCC are estimated to be $\$7.5\bar{B}$.

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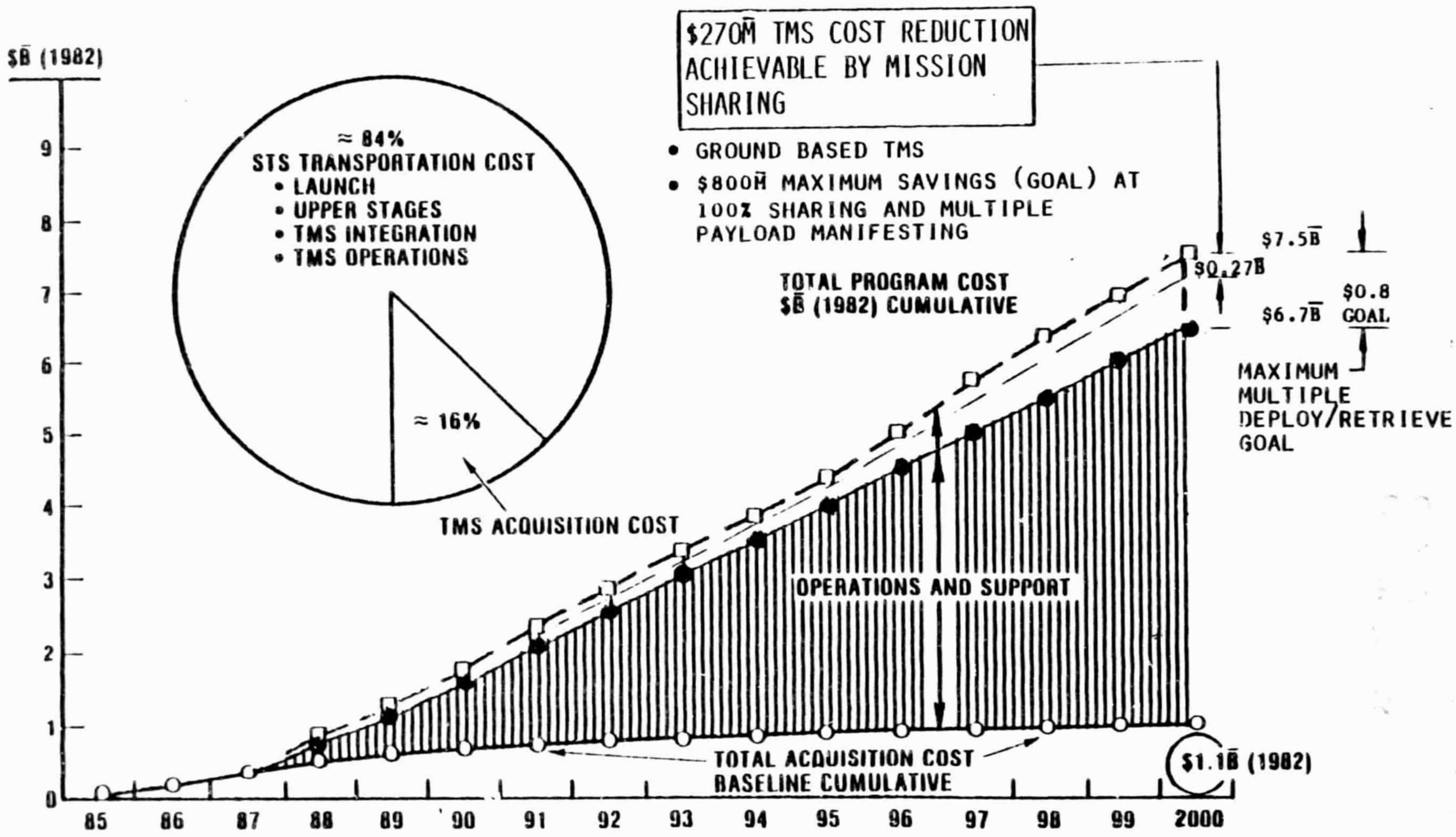
STS TRANSPORTATION COST DRIVES TMS PROGRAM COST



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BENEFIT/COST INSENSITIVE TO ACQUISITION COST ESTIMATES

An independent parametric cost estimate of TMS acquisition costs, developed from the USAF Space Division Unmanned Spacecraft Cost Model adjusted downward to compensate for changes, indicated a total acquisition cost of $\approx$ \$1.3 B_{82}. Since acquisition costs account for only about 15% of total program cost ($\approx$ \$7.5 B_{82}), the difference in acquisition cost estimates is not material to the justification decision.

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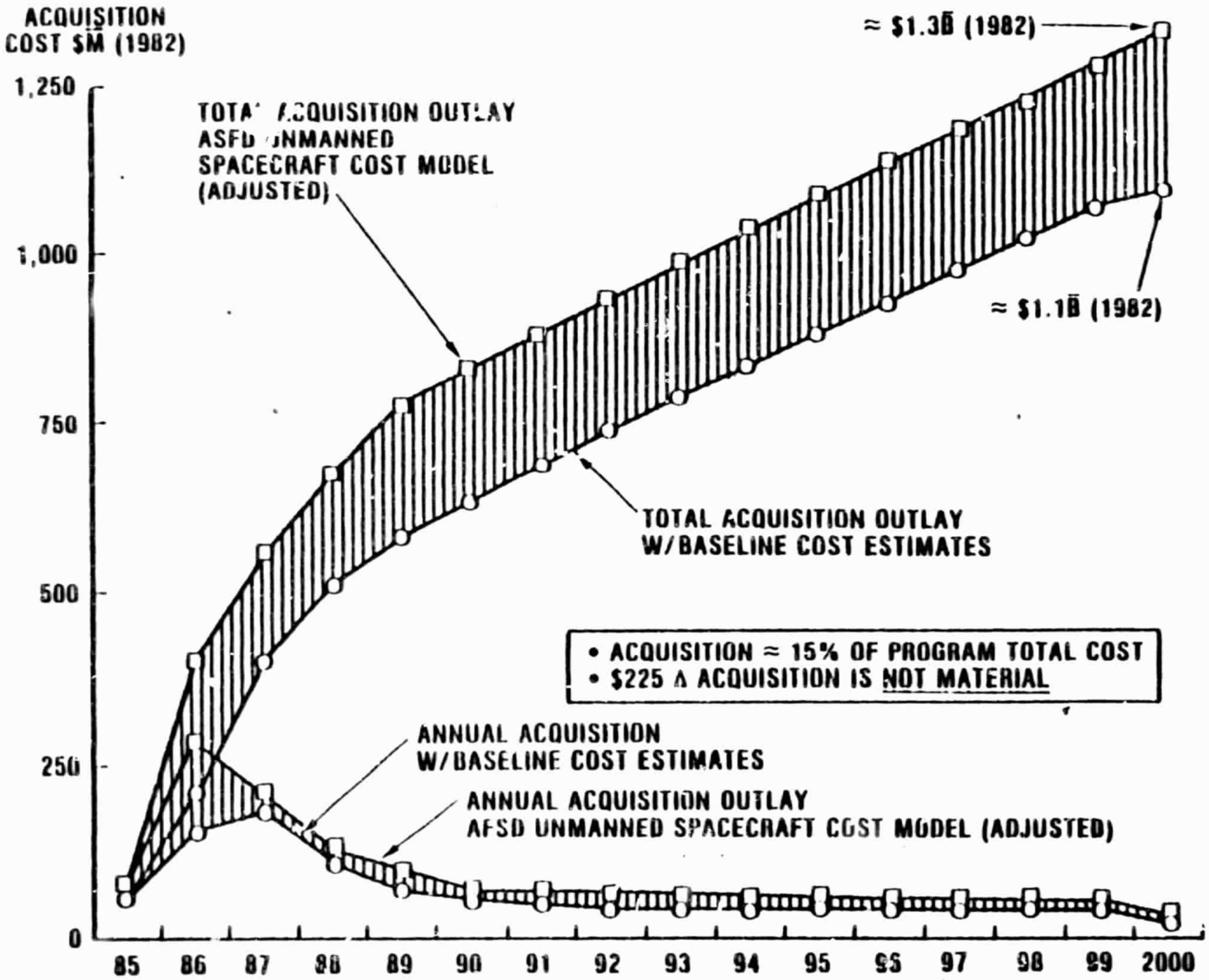
BENEFIT/COST INSENSITIVE TO ACQUISITION COST ESTIMATES



92SSV126173

- SATELLITE DEPLOYMENT/RETRIEVAL
  - SATELLITE SERVICING
    - TMS ACQUISITION & OPERATIONS COST
      - TMS NET BENEFITS ASSESSMENT

TMS VS. INTEGRAL PROPULSION, LEO AND POLAR, DEPLOY, RETRIEVE AND SERVICE FUNCTIONS

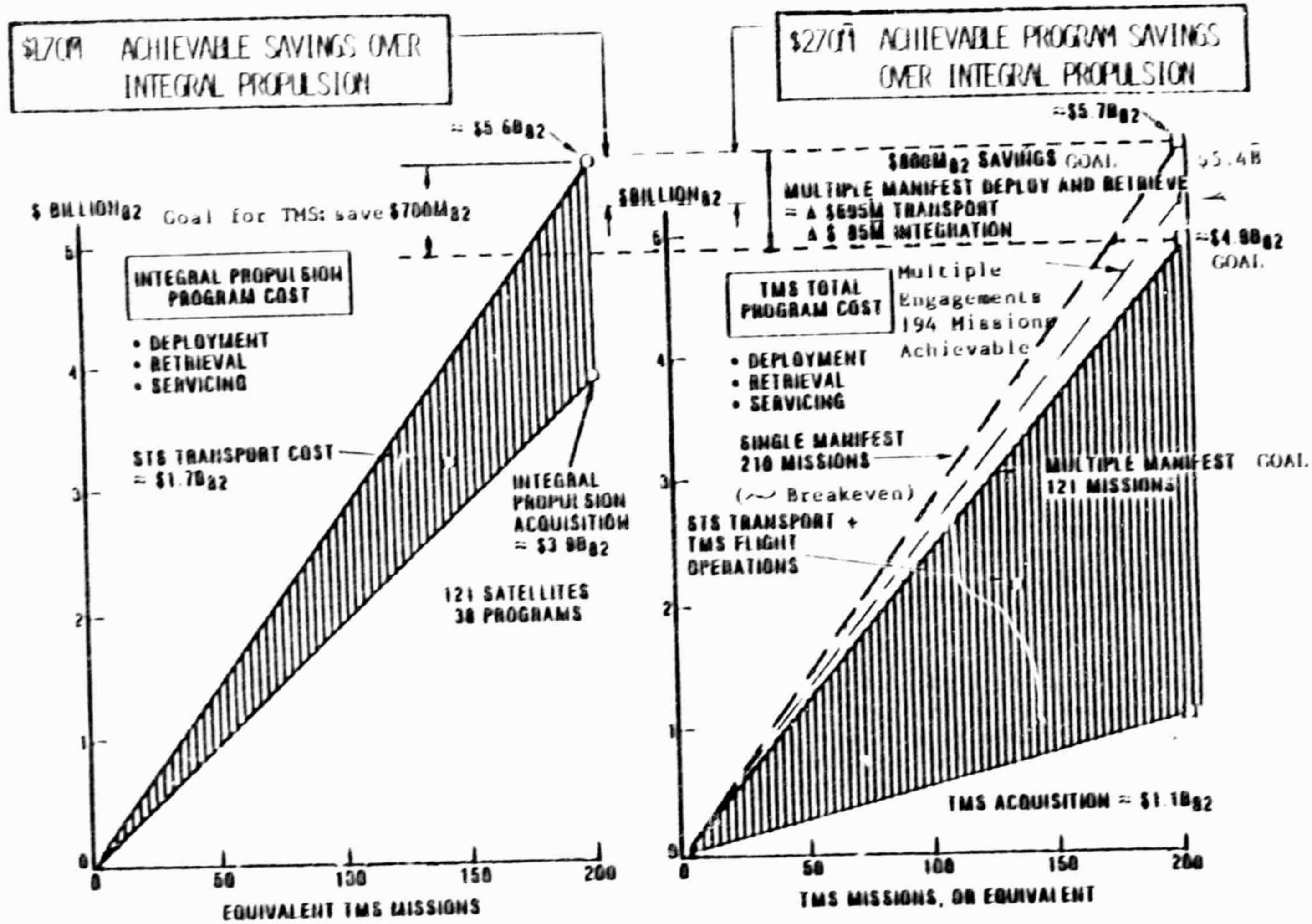
TMS SAVES $170\bar{M}$ OVER INTEGRAL PROPULSION

Parametric cost estimates for two alternative means of LEO and polar satellite deploymen , satellite retrieval, and propulsive functions incident to satellite servicing -- teleoperator maneuvering system or integral spacecraft propulsion -- indicate that multiple manifesting of the deployment and retrieval functions show a $270\bar{M}$ cost reduction in TMS total program cost. This reduction is achieved by reducing the per unit STS transportation and integration charges; no per unit reduction in TMS flight operations charges have been included, however, and this could conceivably reduce TMS total program cost even further.

Though it would be found that spacecraft maintenance offered the greatest potential dollar savings to the payload user, it was recognized that this would require a willingness on the part of the payload user to accept the economics analysis as valid, become convinced by on orbit demonstrations of TMS remote servicing capabilities, and redesign spacecraft to be maintainable, all of which could take many years to mature.

On the other hand, use of TMS as a reusable propulsion stage, if shown to be profitable, had considerable potential for near term utilization. Consequently, this became the first priority task in the study. It has been stated in three studies by other contractors that TMS was an even trade with integral propulsion, when transport costs were included. Brief mention was made of possible benefits of shared deploy/retrieve missions, but the subject was not developed. Rockwell found this to be the central issue upon which TMS benefits turned. By an intensive analysis of both multiple manifesting, in which two or more payloads are deployed, and shared deploy/retrieve missions, a cost saving of $170\bar{M}$ was obtained by TMS over integral propulsion.

TMS VS INTEGRAL PROPULSION, LEO AND POLAR, DEPLOY, RETRIEVE AND SERVICE FUNCTIONS



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ON-ORBIT MAINTENANCE EFFECTS, LEO AND POLAR SATELLITES

Earlier discussion developed the rationale underlying the serviceable satellite population projections. Anticipated growth in total satellite population by the end of the century represents a near doubling of the current inventory of operational satellites. Of course, not all satellites will be designed for serviceability by the end of the century, thus two "acceptance" (of the serviceable design philosophy) population projections have been made.

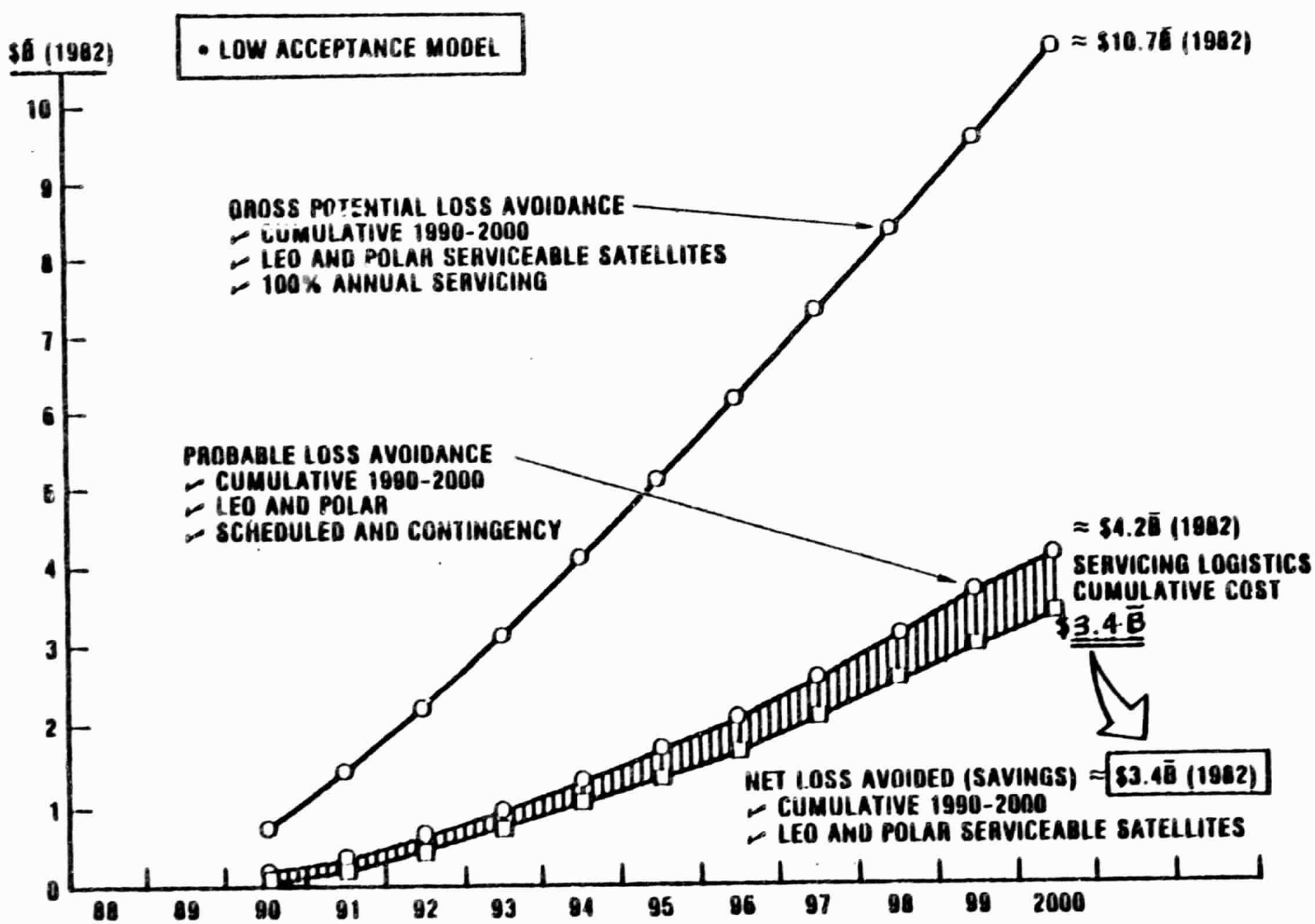
In the "low acceptance" projection, some thirty LEO satellites, including all of the astronomic observatory class, are expected to be designed for serviceability. The expected loss, developed on a satellite by satellite generic basis, in the LEO and Polar satellite classes will probably exceed $2 $\overline{B}_{82}$ per year by the end of the century, and will probably cumulate to approximately $16 $\overline{B}_{82}$ over the final decade of the century.

Assuming that TMS servicing function becomes available in 1990, nearly $11 $\overline{B}_{82}$ of the cumulative expected loss could be restored (avoided) by continuous satellite servicing in the LEO and Polar inclinations, and an additional $4 $\overline{B}_{82}$ could be avoided by continuous satellite servicing in geosynchronous orbit.

The TMS mission model includes only 89 LEO and Polar servicing engagements during the 1990-2000 era with an additional eight servicing engagements at GEO. A large portion of the LEO servicing engagements are dedicated to materials processing satellites (MPS); thus, only a fraction of the gross potential loss avoidance could actually be realized since servicing is considerably less than 100% complete. An estimated $4 + $\overline{B}_{82}$ in actual satellite losses will restored as a result of TMS servicing, and after allowing approximately $800 $\overline{M}_{82}$ for spares-associated costs (transportation costs to perform the servicing are included in the total program costs estimated earlier and are not included here), a net loss avoidance (cost saving to the satellite program sponsors) of $3.4 $\overline{B}_{82}$ can be expected to accrue to commercial, scientific and military users of LEO and Polar satellites.

ON-ORBIT MAINTENANCE EFFECTS, LEO AND POLAR SATELLITES

POTENTIAL LOSS AVOIDANCE EQUALS EXPECTED LOSS IN MISSION VALUE, SERVICEABLE SATELLITES



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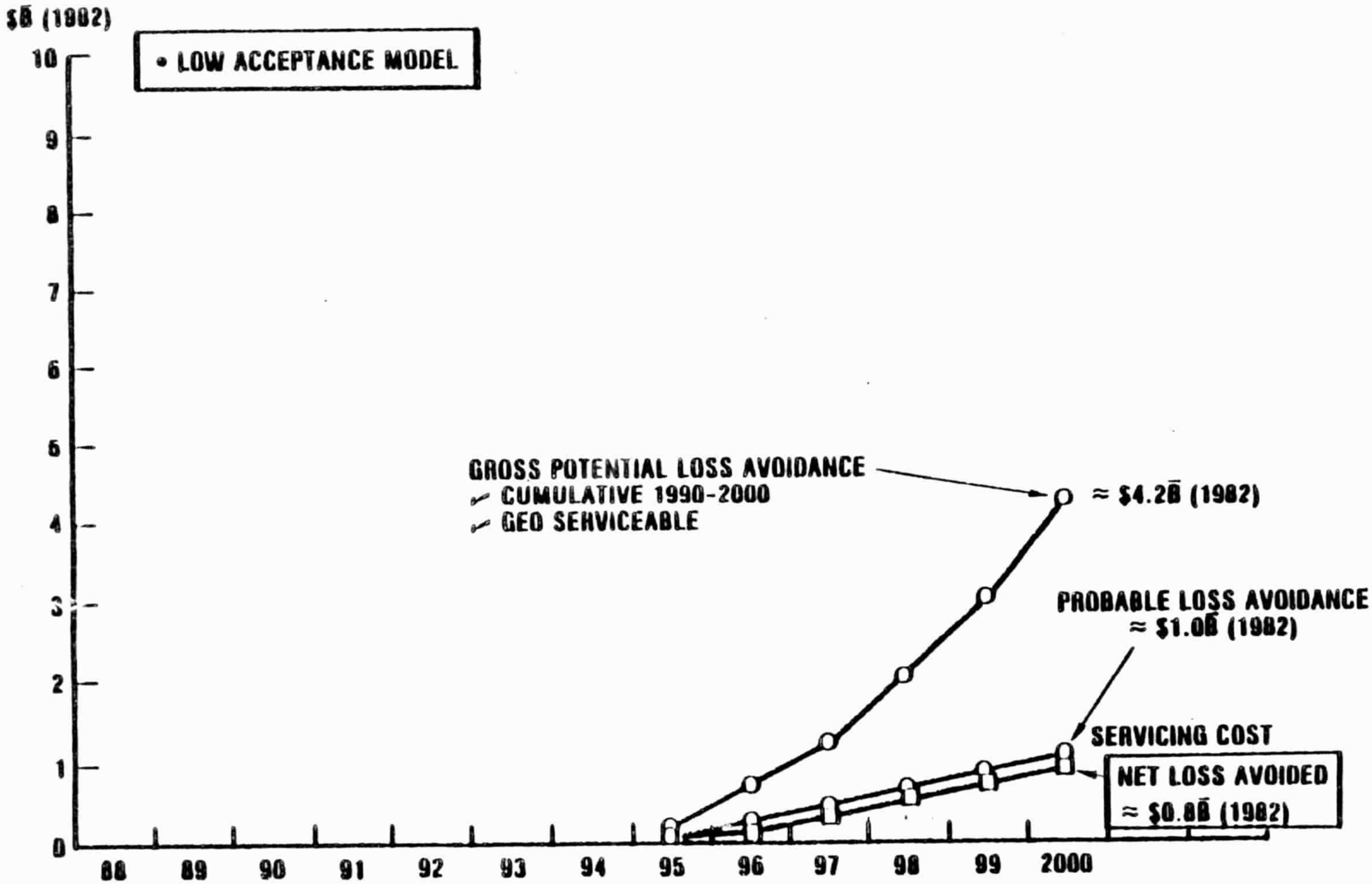
ON-ORBIT MAINTENANCE EFFECTS, GEO SATELLITES

In both the "low acceptance" and "high acceptance" serviceable satellite projections, adoption of the refurbishable satellite design philosophy is expected to be materially slower at GEO than at either LEO or Polar orientations. GEO servicing requires two essential prerequisites for economic feasibility: (1) demonstrated capability of successful satellite servicing in LEO, and (2) concentration of capital, e.g., platforms or clusters, to enable effective servicing of ten or more communications satellite equivalents. Neither of these conditions are expected to obtain until the late 1980's (optimistically) and the design cycle of GEO satellites suggests that a mid-1990's servicing encounter is probably the earliest realistic expectation.

The slow response in adopting a "design for refurbishability" philosophy among GEO satellite producers limits the gross potential for loss avoidance to considerably less than that of the LEO and Polar users, even though the economic value of capital in place at GEO is expected to grow rapidly. Only eight GEO servicing engagements are included in the TMS mission model, the earliest of those a non-economic capability demonstration; thus, only about \$1 $\overline{B}_{82}$ of loss will be restored by GEO servicing to the end of the century and the net saving will approximate \$800 $\overline{M}_{82}$.

ON-ORBIT MAINTENANCE EFFECTS, GEO SATELLITES

POTENTIAL LOSS AVOIDANCE EQUALS EXPECTED LOSS IN MISSION VALUE, SERVICEABLE SATELLITES



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ANNUAL COST/BENEFIT (CASH FLOW) PROFILE

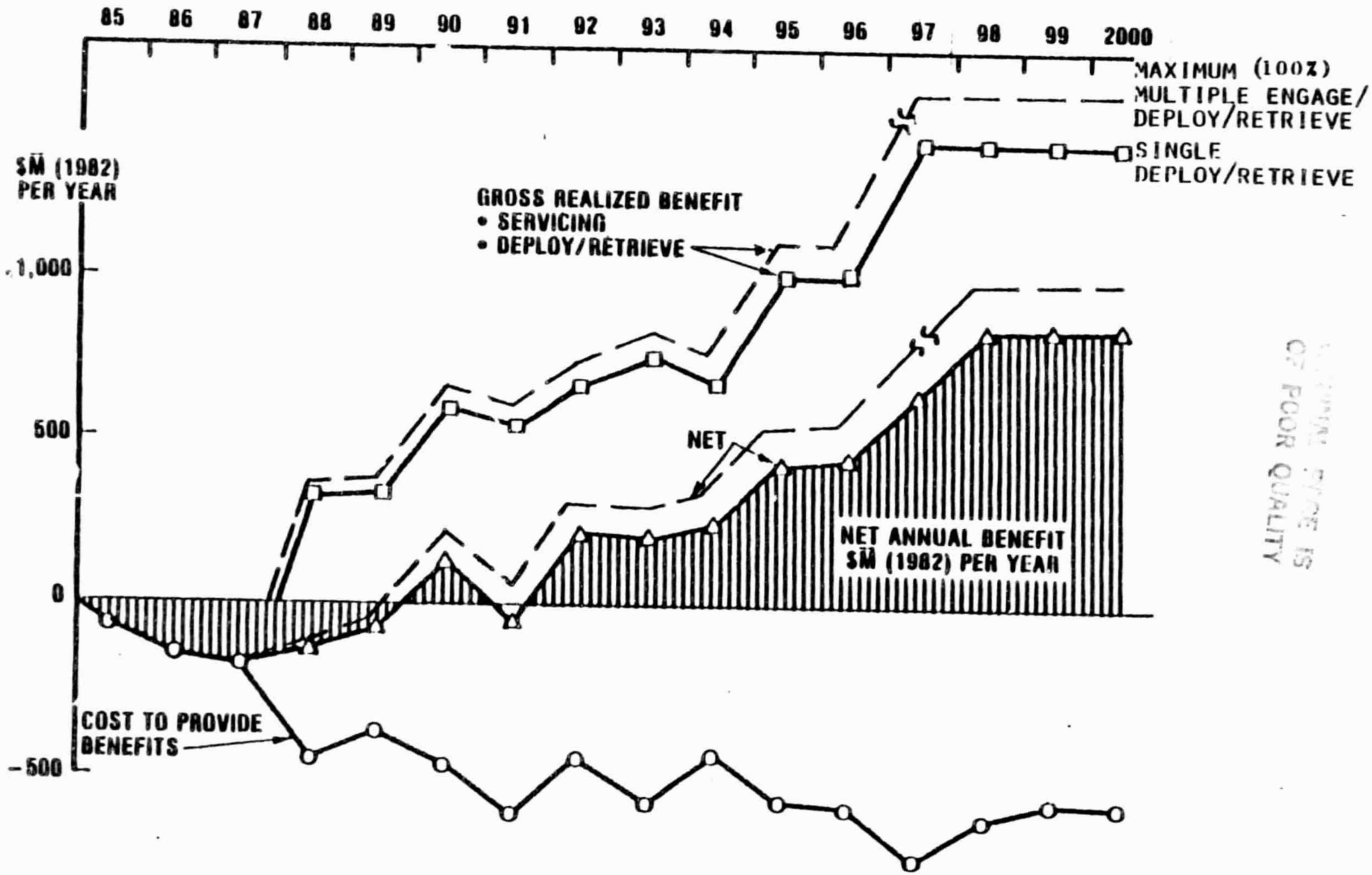
Annual cash outlays (cost to provide benefits) and annual realized benefits (resulting primarily from satellite servicing) have been combined to derive the net annual cash flow profile which would result from a TMS Authority to Proceed.

The cost to provide benefits includes both the acquisition investment (DDT&E plus production) and the recurring TMS flight operations and STS integration and transportation charges for the TMS in a ground-based mode.

The realized benefit profile includes the cost savings accruing from satellite servicing at LEO, Polar and GEO, and also includes the savings (cost avoidance) which would arise from replacement of integral propulsion systems by the TMS (dashed lines).

The net annual benefit profile indicates a cost savings of approximately $\$800\bar{M}_{82}$ per year by the latter years of the century, assuming single manifesting of deployed payloads, an estimated saving of $\$830\bar{M}$ with achievable mission sharing, and a saving of approximately $\$880\bar{M}$ with 100% mission sharing, including multiple payload manifesting.

ANNUAL COST/BENEFIT (CASH FLOW) PROFILE ($M 1982/YEAR)



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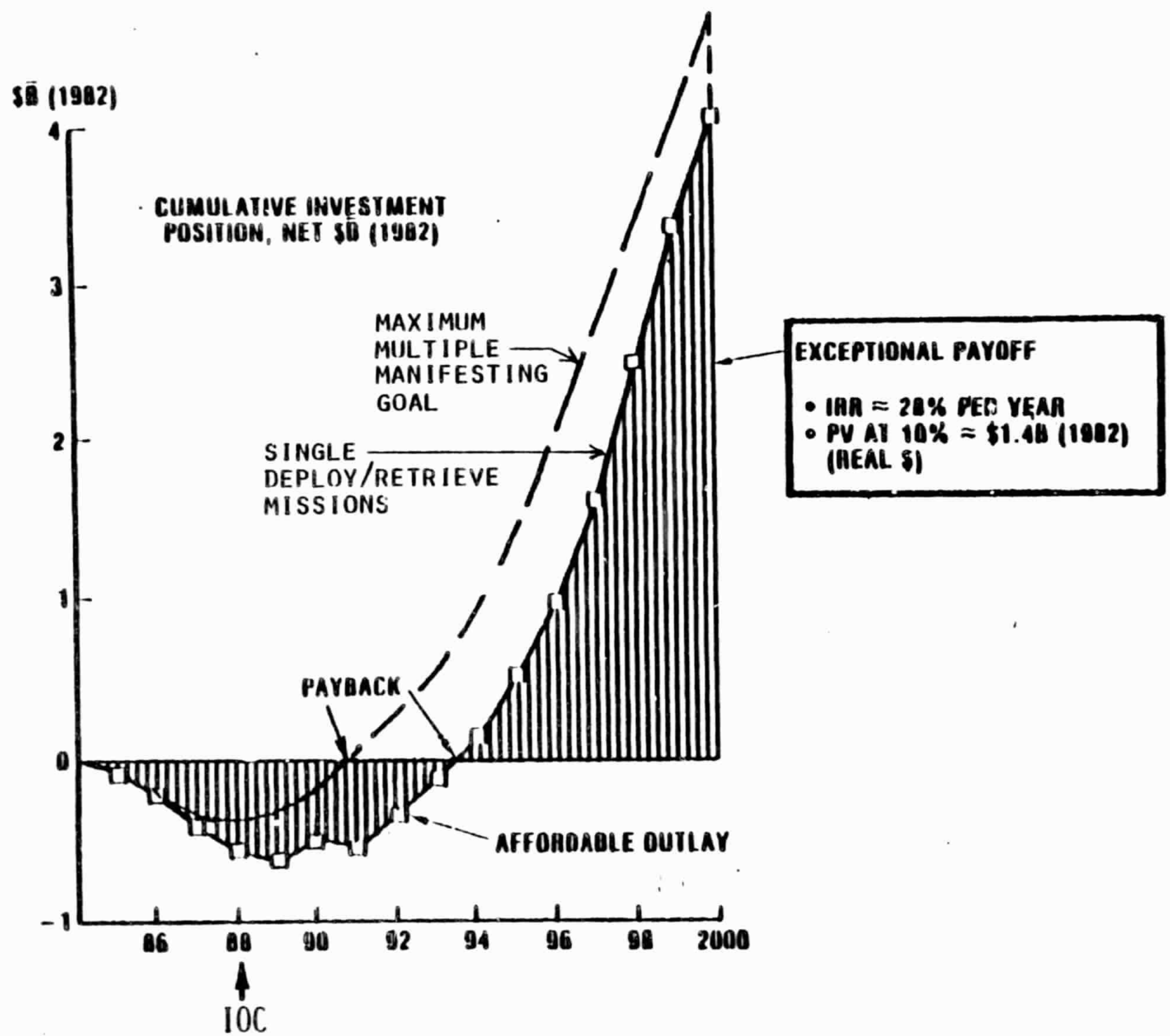
TMS BENEFITS ASSESSMENT: BOTTOM LINE

The cumulative cash investment position is derived from the net annual benefit (cash flow) profile, and indicates that the TMS proposal is commercially viable. The net investment never exceeds $-\$700\bar{M}_{82}$ and payback can be expected within a few years of initial operating capability. The exceptional pay-off to the TMS proposal, however, begins to be fully realized in the last half of the next decade, when satellite servicing becomes "big business."

TMS BENEFITS ASSESSMENT: BOTTOMLINE



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